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Transformation and Transition: DARPA's Role in Fostering an Emerging Revolution in Military Affairs
Volume 2 – Detailed Assessments

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PREFACE

The Institute for Defense Analyses was tasked by the Defense Advanced Research Projects Agency (DARPA) to assess the agency's role in effecting fundamental change in defense capabilities for the advantage of US military forces, focusing on what has been termed the post-Cold War "Revolution in Military Affairs" (RMA). The Overall Assessment from this task was documented in *Transformation and Transition: DARPA's Role in Fostering An Emerging Revolution in Military Affairs*, Volume I, dated April 2003.[1] The overall assessment was derived from a set of detailed case studies of DARPA program areas that were identified as being major factors in the RMA. Volume II documents the individual case studies of the technology areas that were the basis of the overall assessment.

The authors wish to thank John Jennings, the DARPA task manager for this project, for his detailed review and comments on all of the chapters in this volume. His review led to greatly improved clarity on our part in both depicting the flow of technology development and the roles of various organizations and individuals in this flow. He also provided a superb sounding board for the observations and conclusions we draw as to the factors that either fostered or impeded the movement of these technologies into military application.

For each chapter the individual authors interviewed numerous participants in the development and the management of specific technologies and their applications. Throughout these chapters we cite interviews from many of these individuals who were most forthcoming and generous with their time. Some of these individuals provided insights and details about several technology thrusts and applications in which they were directly involved in overseeing—especially former Secretary of Defense and former Under Secretary of Defense for Research and Engineering William Perry; former Under Secretary for Research and Engineering Malcolm Currie and former DARPA Directors Steven Lukasik, George Heilmeier, Robert Fossum and Larry Lynn. In addition there were many DARPA office and program managers, former military service technology managers—both civilian and military officers—and a number of technologists, strategic

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1 Richard H. Van Atta and Michael J. Lippitz with Jasper C. Lupo, Robert B. Mahoney and Jack Nunn, *Transformation and Transition: DARPA's Role in Fostering An Emerging Revolution in Military Affairs*, Volume I—Overall Assessment, Alexandria, Virginia: Institute for Defense Analyses, IDA Paper P-3698, April 2003.

thinkers, military service users, and defense industry managers who provided valuable perspectives regarding specific technologies, programs, and applications. The authors wish to thank all of these contributors for the invaluable data and the candid observations they provided.

We recognize that it is difficult to adequately represent the views—and indeed at times differing perspectives—even in these more detailed cases studies. Moreover, we are aware that there are many other contributions made by individuals and organizations to the various technology developments covered in these chapters that we did not include. Retrospectives such as those contained in this volume always will be selective and only partial representations of reality. We endeavored to capture these developments in as an objective and accurate manner as possible within constraints of time and space available in such a document. Any errors in representation of history are solely those of the authors and not the contributors, reviewers, or current DARPA management.

CONTENTS

TABLES

FIGURES

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INTRODUCTION AND SUMMARY

OVERVIEW OF DARPA AND THE RMA

DARPA's primary mission is to foster advanced technologies and systems that create "revolutionary" advantages for the US military. Consistent with this mission, DARPA is independent from the Military Services and pursues generally higher-risk, higher-payoff research and development (R&D) projects. DARPA program managers are encouraged to challenge existing approaches to warfighting and to seek results rather than just explore ideas. Hence, in addition to supporting technology and component development, on occasion DARPA funds the integration of large-scale "systems of systems" in order to demonstrate "disruptive capabilities." Disruptive capabilities are more than just new technologies; they are transformations in operations and strategy enabled by synergistic combinations of technologies.

The combination of stealth, standoff precision strike, and advanced intelligence, surveillance and reconnaissance (ISR) demonstrated in Operation Desert Storm is an example of disruptive capabilities. It allowed the US to change the rules of conventional warfare in a manner that many consider to be the forefront of a broad "Revolution in Military Affairs" (RMA) in which the ability to exercise military control is shifting from forces with the best or the most individual weapons systems toward forces with better information and greater ability to quickly plan, coordinate, and accurately attack.

This report provides detailed individual discussions of DARPA-sponsored developments of disruptive technologies and capabilities in the areas of stealth, standoff precision strike, and advanced ISR and hence to an emerging RMA. It is a complement to the previously published *Transformation and Transition: DARPA's Role in Fostering An Emerging Revolution in Military Affairs*, Volume I, which gave an overall assessment of these developments and highlighted and discussed management practices that facilitated the development and exploitation of these disruptive capabilities.

Volume II provides chapters covering these technology thrusts as listed below:

Chapter I.	Stealth Combat Aircraft
Chapter II.	Developing the Navy's 21st Century Ships
Chapter III.	The Development and Deployment of Precision Guided Munitions (PGMs) for Standoff Attack
Chapter IV.	Assault Breaker
Chapter V.	DARPA's Role in the Development of Precision Weapons in the Post-Cold War Era
Chapter VI.	Unmanned Aerial Vehicles
Chapter VII.	Discoverer II

The individual chapters generally cover first Stealth (Chapter I), Standoff Precision strike (Chapters III–V), and ISR (Chapters VI and VII). Chapter II on Navy ships begins with a focus on stealth (the Sea Shadow), but then changes in focus to standoff strike, as the application focus became one of providing a naval capability for littoral strike (Arsenal Ship). The substantive shift in this chapter represents in the small a characteristic of the set of technology developments reviewed in this study: They were an interlinked set of technology developments that provided much larger "system of systems" capabilities. Stealth enabled the use of other technologies for strike. ISR provided by sensor developments as well as alternative platforms for their use—unmanned aerial vehicles and satellites—enabled standoff precision strike. Moreover, these technologies have been shown to be highly fungible across missions and applications. The initial focus for these developments was the Cold War and the specific threat of the Soviet Union and Warsaw Pact. The technologies and the integrated capabilities built upon them have become key elements of the post-Cold War military capabilities that address fundamentally different threats. The evolution of these technologies, as depicted in these chapters, captures some of the perturbations caused by this shift in the global arena and their effects on developing and implementing technology solutions to national security problems.

IMPLEMENTING DISRUPTIVE CAPABILITIES

As discussed in Volume I, DARPA played a formative role in central technologies of the Offset Strategy—stealth; standoff precision strike; and advanced intelligence, surveillance, and reconnaissance (ISR)—not only by supporting the development of technologies but also by following through to turn technologies into military capabilities. The individual chapters provide further detail on these developments.

Stealth Combat Aircraft (Chapter I)

Based on a concept from the Office of the Director of Defense Research and Engineering, DARPA solicited ideas from industry and funded studies on the possibility of building stealth combat aircraft. The stealth concept—essentially eliminating the electronic observable characteristics of military systems—had been employed in classified reconnaissance aircraft but not in weapons platforms. Lockheed and Northrop presented credible breakthrough concepts. Given the magnitude of the proposed advances, DARPA decided that a full-scale flight demonstration would be needed to make the results convincing. Under pressure, the Air Force agreed to co-fund the demonstration program—HAVE BLUE—provided that subsequent acquisition funding would not come out of higher priority Air Force programs. (At the time, the Air Force saw limited value in a stealthy combat aircraft, given its inherent limitations in speed and maneuverability and the fact that it would only fly at night.)

Lockheed was selected to build two HAVE BLUE prototype aircraft to test out stealth concepts, while meeting limited but realistic operational requirements. Successful flights of the HAVE BLUE planes persuaded Under Secretary of Defense William J. Perry to initiate a stealth aircraft acquisition program, Senior Trend, which became the F-117A. In order to obtain the largest possible technical lead, the development program was conducted in high secrecy, and the program was designed to deliver the first operating aircraft in only 4 years, forgoing the normal development and prototyping stages. Dr. Perry closely monitored the program through a special executive review panel, which he chaired. Classified subcommittees of the House and Senate Armed Services Committees were established, as well as an umbrella program office that included stealth programs for ships, satellites, helicopters, tanks, reconnaissance aircraft, cruise missiles, unmanned aerial vehicles, strategic bombers, and stealth countermeasures.

The Air Force made provisions to deploy an operational wing of F-117As, undertook an extensive testing program, and developed new operational practices to take advantage of its special capabilities. In 1991, F-117A stealth aircraft helped the US achieve early air superiority in Operation Desert Storm in the face of the same type of Soviet integrated anti-aircraft systems that had caused so much trouble for US-made tactical aircraft in Vietnam and the 1973 Yom Kippur War. It was exactly the type of "secret weapon" capability DARPA and top OSD leadership had envisioned.

Naval Stealth and Standoff Precision Strike (Chapter II)

Starting in the 1970s, DARPA and the Navy undertook a series of surface ship programs—Sea Shadow, Arsenal Ship, and DD-21—aimed at revolutionary naval combat capabilities. But without a strong impetus for change, consistent high-level imprimatur, a focused mission (distinct from existing ships), and an independent development organization, the Navy has neither fully developed nor acquired the envisioned disruptive capabilities.

The Sea Shadow began in 1978 as a highly classified program in the Lockheed Skunk Works, leveraging stealth developments for the F-117A. Under contract to DARPA, the Lockheed team developed a scale model of a stealth surface ship. Under Secretary Perry was impressed enough by initial data from this model that he ordered the Navy to fund R&D for a full-size stealth ship even though the Navy's leadership was not interested in it, due to its cost and the challenge it posed to existing ships. (Perry addressed Navy budget concerns by keeping funding stable for other Navy ship programs.) Under a new DARPA contract, the Sea Shadow was built and tested for 2 years, yielding excellent results. However, Navy leadership terminated further investment in Sea Shadow when they interpreted a reduction in funding for the DDG-51 Destroyer by the next administration as a move to redirect funds to pay for Sea Shadow.

To support the Navy's post-Cold War concepts for projecting naval power ashore, Admiral Mike Boorda (Chief of Naval Operations) and John Douglass (Assistant Secretary of the Navy for Research, Development and Acquisition) strongly supported the concept of a sea-based precision strike platform. But they were skeptical about the Navy's ability internally to embrace such a disruptive concept—it threatened the role of carrier-based naval aviation in many early shore engagements—and turned to DARPA to help develop what became known as the Arsenal Ship. DARPA Director Larry Lynn approved DARPA taking on the program, although he was concerned with the Navy's poor record in implementing DARPA-developed technology.

DARPA had already developed many of the necessary Arsenal Ship technologies during the Sea Shadow Program. To deliver munitions early in an engagement, Arsenal Ship would have to be forward-deployed and under the control of the theater commander. It would require secure communications, reliable data linkages, and a remote targeting and launch system. It would also need to have a low radar signature and be survivable. Acquisition goals included a life-cycle cost less than one-half of a traditional surface ship, suggesting that the ship would have to be highly automated so that it could be operated by a very small crew (though small crews tend to reduce survivability by making damage control—e.g., fighting fires—more difficult).

DARPA specified a relatively small number of broad performance characteristics and assigned full design responsibility to competing contractor teams. The government program office was kept small, and the contractor was free to apply modern, efficient, management practices. A top-level DARPA and Navy Executive Committee reviewed the program at major decision milestones, evaluated program costs, and provided redirection as necessary. But with the untimely death of Admiral Boorda, the Arsenal Ship lost a strong advocate. Soon thereafter, the Navy changed the nature of the program, redefining it as a demonstrator for risk reduction. Congress then reduced its funding, and the Secretary of the Navy canceled the program.

The Navy has continued to consider but not implement radical new ship designs aimed at enabling disruptive capabilities. After canceling the Arsenal Ship, the Navy initiated the DD-21 Program, promoted as the first of a family of surface combatant ships to replace the fleet designed for sea control in the Cold War environment. DD-21 was to be armed with land attack weapons like Arsenal Ship and survivability features from Sea Shadow, and it was to be highly automated. But in November 2001, the Navy shifted again, issuing a revised Request for Proposal (RFP) for the Future Surface Combatant Program, with DD-21 renamed DD(X) with many of the features explored earlier in the DD-21 program. On April 29, 2002, Northrop Grumman Ship Systems was selected as the lead design agent for DD(X).

Standoff Precision Strike (Chapters III–V)

In the 1970s, DARPA-sponsored concept development studies defined alternatives for defeating massed Soviet armor using precision guided conventional weapons rather than nuclear weapons. By combining several ideas from different sources, DARPA's Robert Moore, at that time Deputy Director of DARPA's Tactical Technology Office (TTO), conceived the Integrated Target Acquisition and Strike System

(ITASS) concept for attacking armor deep in enemy territory using airborne reconnaissance to guide long-range missiles carrying terminally guided submunitions. The Defense Science Board reviewed an array of technologies, concluded that they could be integrated, and recommended a demonstration. The DARPA Assault Breaker Program, which embodied the ITASS concept, supported contractors in bringing various component technologies up to the necessary performance levels, tested different contractor approaches in parallel, and attempted gradually more complex integrations. In the end, a standoff precision strike capability was demonstrated in December 1982 at the White Sands Missile Test Range. A missile guided by airborne radar dispensed five submunitions above five target tanks scattered in a field. Using terminal guidance, the submunitions homed in on the targets and made five direct hits.

Despite the technical success of Assault Breaker, implementation as an integrated, joint capability proved to be circuitous and incomplete. The Air Force focused on delivering munitions from manned aircraft, while the Army focused on ground systems and helicopters. However, joint programs created in 1983 in response to congressional pressure led to several system developments based on Assault Breaker. The Joint Surveillance Target Attack Radar System (JSTARS) flight test aircraft and the Joint Tactical Missile System (JTACMS, which became Army Tactical Missile System, ATACMS) were employed successfully in Desert Storm. Terminally-guided precision munitions are beginning to be deployed today, but not as part of the type of integrated reconnaissance/strike capability envisioned by Assault Breaker.

After Assault Breaker, DARPA turned its attention to the mission of attacking mobile, elusive targets, such as Soviet mobile missiles. The DARPA Smart Weapons Program sought to develop weapons that could search large areas and precisely deliver munitions on targets. In Desert Storm, Iraqi Scud missiles could not be found and destroyed with manned aircraft in spite of a massive sortie rate. To address the problem, an accelerated Smart Weapons spin-off program (Thirsty Warrior) was initiated to integrate Smart Weapons capabilities into a cruise missile. However, the impetus for deployment waned rapidly after the war, and “smart weapons”—precision guided weapons capable of both searching for and attacking mobile and elusive targets—remain an unfilled prospect.

Intelligence, Surveillance and Reconnaissance (ISR)

Early ISR systems were largely “national assets” controlled by intelligence organizations. The National Reconnaissance Office (NRO) was established in 1960 to centralize operations and reinforce high-level civilian control. The capabilities of national ISR assets have improved dramatically over the years, but their separation from operating forces; their centralized, hierarchical operating procedures; and classification issues have made it difficult for them to provide timely information to tactical commanders. The information requirements of precision weapons have also increased the demands on ISR systems. Unmanned aerial vehicles (UAVs) and small satellites are two examples of ways that DARPA attempted to address these issues.

Unmanned Aerial Vehicles (Chapter VI)

Experimental DARPA remotely piloted vehicles (RPVs, a type of UAV) were used during the Vietnam War for training and for tactical reconnaissance missions deep behind enemy lines. In 1971, DARPA initiated the Mini-RPV Program to address problems associated with reliability, communications, control, sensors, and operations. Two RPVs resulted from this effort: Praeire and Calere. In 1977, DARPA Director George Heilmeier reported to Congress that DARPA had developed RPVs sufficiently for transition to the Services for acquisition and deployment, and hence the Mini-RPV program was ended.

The path to deployment of RPVs and UAVs by the Services would prove long and difficult. US forces were substantially reduced following US military involvement in Vietnam. This included the elimination of Air Force UAV organizations in 1976. Air Force interest in unmanned platforms shifted to cruise missiles. The Air Force built but never adopted Compass Arrow and Compass Cope UAVs. DARPA and the Navy supported Boeing's Condor but failed to gain support for production. The Army's Aquila Program emerged from the initial DARPA-Army collaboration on Praeire. However, mission requirements imposed by the Army were not controlled, due in part to disputes over which branch of the Army would ultimately own the capability. As a result, the cost of the Aquila program increased almost tenfold, and the Army abandoned the program in 1987. DARPA funded the Amber system, a long endurance UAV with sophisticated sensors, with the Navy joining in after a successful demonstration. In the midst of the Amber program, Congress transferred all UAV research, development, test, and evaluation from the Services and DARPA to a new joint program office. Through the joint program office, both the Army and the Navy shifted their priorities to short-range UAVs that fit their existing operational concepts. The resultant UAVs—Hunter and Outrider—did not involve DARPA. Funding for Amber was cut, and then the program was terminated (though its technology would live on and was later incorporated in the

Gnat 750 and the Predator which received continued funding through another agency). Subsequently, Hunter suffered three test flight crashes, leading to cancellation of that program. The Outrider became bogged down with proliferating requirements from the Army and the Navy, resulting in an expensive system that did not do any particular mission well.

In the US military, the first successful UAV acquisition and deployment occurred when Secretary of the Navy John Lehman directed the acquisition of UAV systems. Two Pioneer systems—an Israeli system based on DARPA's Praeire—were procured in December 1985 for an accelerated testing program and subsequently deployed. Based on the Navy's success, the Army fielded Pioneer. In 1991, Pioneers flew nearly 300 reconnaissance sorties at the beginning of Operation Desert Storm.

Operation Desert Storm highlighted serious deficiencies in airborne ISR, particularly for wide-area coverage. Three endurance UAV concepts were proposed as solutions. The Gnat 750, a version of Amber that was already flying, became known as Tier I. Tier II would be an improved version of Amber which became the Predator UAV; Tier III would be a classified, stealthy, long-range UAV requiring significant technology developments. Concerned about the affordability of the Tier III proposal, DoD leadership launched an internal review headed by Deputy Under Secretary Larry Lynn. The 3-month study, which covered all wide-area ISR including satellite and airborne, concluded that (1) there needed to be central leadership in UAVs; (2) Tier II should be accelerated; and (3) Tier III should be terminated and replaced by "Tier II+"—a large UAV with a unit cost of $10 million. Lynn did not believe that the Services could maintain the $10 million cost focus of Tier II+ and persuaded DARPA Director Gary Denman to have DARPA manage the program. In the meantime, Lockheed submitted an unsolicited proposal for development of Dark Star, which became known as "Tier III-", a stealthy UAV for the penetrating reconnaissance role, but with the same $10 million cost objective. OSD decided to proceed with Tier II, Tier II+ and Tier III-programs, with funding coming primarily from the newly created Defense Airborne Reconnaissance Office (DARO), the realization of Lynn's first recommendation.

The Tier II, known as Predator, and Tier II+, Global Hawk, became fielded systems. The Tier III- Dark Star was canceled due to flight test failures and budget overruns. The Predator (Tier II) was delivered for user experimentation in just 6 months using the then experimental Advanced Concept Technology Demonstration (ACTD) method, which allowed a streamlined management and oversight process, early participation of the user community, and a tight schedule. For Global Hawk (Tier II+), DARPA pioneered several new acquisition methods that allowed traditional rules and regulations to be waived in favor of greater contractor design responsibility and management authority. Predator was successfully employed in Bosnia (just a year after its first flight), Kosovo, and the no-fly zone in Iraq. Both Predator and Global Hawk were used in Afghanistan—including the use of Predator as a weapons platform firing Hellfire missiles—despite the fact that they were still prototypes provided to regional combatant commanders on an experimental basis.

Discoverer II: Space-Based Radar Lightsat (Chapter VII)

A 1997 DARPA-sponsored study proposed developing an experimental small light satellite (lightsat) space-based radar, founded on DARPA technologies, which would be capable of ground moving target indication and synthetic aperture radar imaging. Named Discoverer II, the system was intended to demonstrate the following capabilities:

- Deep, broad-area, near continuous, near real-time, tracking of ground mobile forces
- High resolution target classification with three-dimensional position information to support precision targeting
- Direct tasking by and data downlink to joint task force commanders

Due to perceived overlap with NRO missions, a joint DARPA-Air Force-NRO program office was established to develop Discoverer II. In parallel, the Army was to provide an interface for ground force commanders. However, because of its high cost (about a billion dollars), Congress viewed Discoverer II as an acquisition program, not a demonstration, and demanded the formal documentation typically required for a major new start. Ultimately, Discoverer II was canceled, although the capabilities envisioned for it remain DoD priorities.

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I. STEALTH COMBAT AIRCRAFT

Michael J. Lippitz and Richard H. Van Atta

Superiority in conventional aviation had been one of the United States' primary conventional force advantages since 1944. During the Vietnam War, it became apparent that Soviet integrated air defense systems (IADS) challenged this superiority. While it was possible to counter Soviet IADS using jamming, defense suppression, and other active means, this required a very high level of effort. A case in point is the 1972 raid in which F-4 Phantoms firing laser guided bombs destroyed the Paul Doumer Bridge. Payloads during the primary raid were carried by 16 F-4s. They were accompanied by 8 F-4s that dropped chaff, 4 EB-66 electronic countermeasures aircraft, and 15 F-105G Wild Weasel aircraft to attack the radars that guided surface-to-air missiles. More aircraft were deployed to protect the primary mission than accomplished the attack.[1]

The 1973 Middle East War provided an additional demonstration of the potential lethality of modern IADS. Israel lost more than 100 combat aircraft—a significant fraction of its front line posture—in only 18 days. Egyptian air defenses were not neutralized until late in the war, and then only by Israeli ground forces.[2] Israel's American-made aircraft were among the most advanced and capable in the US fleet, with capable pilots. If the NATO air forces were to suffer the same loss ratios against the Warsaw Pact, they would be destroyed in weeks.[3] Various concept development studies of Central European battlefield scenarios also predicted that NATO forces would be defeated, in part because of the effectiveness of the Soviet/Warsaw Pact IADS.[4]

In 1974, Chuck Myers, director of Air Warfare Programs in the Office of the Director of Defense Research and Engineering (DDR&E), mentioned to Robert Moore, Deputy Director of DARPA's Tactical Technology Office (TTO), an idea he called the "Harvey concept," named after the invisible rabbit in a popular play and movie. The concept was to create a manned tactical combat aircraft with greatly reduced radar, infrared, acoustic, and visual signatures. A primary objective was to use only passive

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1 George and Meredith Friedman, *The Future of War. Power, Technology and American World Dominance in the Twenty-First Century,* New York: St. Martin's Griffin, 1996, p. 239.

2 David C. Aronstein and Albert C. Piccirillo, *Have Blue and the F-117A: Evolution of the Stealth Fighter,* Reston, VA: American Institute of Aeronautics and Astronautics, Inc., 1997, p. 11.

3 Ben Rich and Leo Janos, *Skunk Works*, Boston: Little, Brown and Company, 1994, p. 17.

4 Aronstein and Piccirillo, p. 14. See also Volume I of this report, Section IIA.

measures (coatings and shaping) rather than depending on support aircraft carrying jammers.[5] By making it difficult for an enemy to find and attack such a plane, new types of deep air attacks would be possible, replacing the "air armada" tactics that had become the norm in Air Force and Navy aviation.

The Harvey idea was not entirely new, as low observable characteristics and radar-absorbing materials had been employed in classified reconnaissance aircraft (both manned and unmanned) during the 1960s. However, previous efforts addressed stealth as an afterthought and incorporated stealth features to the extent that aerodynamic performance was not significantly affected.[6] Furthermore, there were no serious efforts to employ such capabilities for a weapons platform, though a 1971 Air Force study had recommended undertaking prototyping experiments in order to prove out various laboratory concepts.[7] Myers wanted to fund aircraft companies to propose conceptual designs. Coincidentally, shortly after the Myers-Moore meeting, DDR&E Malcolm Currie sent out a memo stating that he was not satisfied with the innovation he saw coming out of DoD research, and he invited organizations to propose radical new ideas. For DARPA's TTO organization, Moore nominated the "Harvey" idea, renaming it "High Stealth Aircraft."[8]

Around the same time, Ken Perko came to DARPA from the Air Force Systems Command at Wright-Patterson Air Force Base. TTO director Kent Kresa had recruited him to build up a tactical air division within TTO.[9] In the Air Force, Perko had worked on DARPA-sponsored "low-observable" research for drones and remotely piloted vehicles. Moore asked Perko to talk to leading aircraft designers at defense contractors to determine their interest in investigating stealth aircraft. He ultimately funded small preliminary studies at Grumman, McDonnell-Douglas, and Northrop. Three formal study contracts followed, awarded to McDonnell-Douglas, Northrop, and Hughes (for its radar expertise). While these studies were underway, Lockheed's Russ Daniels learned of the

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5 Interview with Robert Moore, July 30, 2001. See also Richard H. Van Atta, Sidney Reed, and Seymour J. Deitchman, *DARPA Technical Accomplishments, Volume II: An Historical Review of Selected DARPA Projects* (IDA Paper P-2429), Alexandria, VA: Institute for Defense Analyses, April 1991, p. 10-4.

6 Aronstein and Piccirillo, p. 10.

7 Ibid., p. 11.

8 The term "stealth" was borrowed from anti-submarine warfare, in which the problem was to prevent submarine detection. The eventual plane built under this program was much larger than had been envisioned by Myers in Project Harvey.

9 Aronstein and Piccirillo, p. 13.

project during a visit with Myers. Lockheed had not been invited to participate initially because it was not considered active in tactical aircraft. Furthermore, Lockheed's work for the CIA on low observables during the 1960s for the SR-71 Blackbird was a closely held secret. Once Lockheed obtained permission from the CIA to share its radar cross section (RCS) results from that program, Ed Martin, director of Lockheed science and engineering, contacted DARPA and requested permission to participate in the first phase concept development. Lockheed's proposal could not be funded because it arrived after the contract competition. Lockheed requested permission to proceed without compensation (and hence without having to share the rights to its technology). After much deliberation, DARPA Director Heilmeier granted this request.[10]

The initial study objectives were to identify precisely the signature levels that would permit a tactical aircraft to avoid detection (with emphasis on radar detection) and to define a technical approach for achieving such levels of reduction in RCS and other signatures. Perko's old Air Force organization, the Remotely Piloted Vehicle System Program Office, managed the contracting and provided technical assistance. McDonnell Douglas was the first to identify what appeared to be appropriate RCS thresholds. Hughes Aircraft confirmed these. DARPA defined these thresholds as program goals.

It was clear that Lockheed and Northrop were far ahead of the others in terms of stealth aircraft design. Northrop had a more comprehensive RCS prediction capability than Lockheed, but, at the time, both capabilities were based on heuristics and empirical testing. However, in 1975, a Lockheed engineer named Denys Overholser came across a 1966 technical paper, "Method of Edge Waves in the Physical Theory of Diffraction," by Pyotr Ufimtsev, the Chief Scientist at the Moscow Institute for Radio Engineering, which had just recently been translated by the Air Force Foreign Technology Division. The paper showed how to predict radar cross sections for certain geometries. Using these formulae, Overholser realized that it would be possible to develop computer software that could predict the RCS of entire aircraft, as long as the aircraft were composed of these distinct geometric shapes. Working on a tight schedule, ECHO I, Lockheed's first computational model for RCS prediction, was completed in less than 6 weeks. Over the course of the stealth program, this code was refined, to include incorporation of other findings from Soviet open literature. RCS models validated the code's predictions.[11]

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10 Ibid., pp. 14–15, Rich and Janos, pp. 23–25, and interviews with Robert Moore, July 30, 2001, and George Heilmeier July 13, 2001. Lockheed aggressively sought to be included, lobbying several high-level OSD and Air Force officials to be brought into the project. (Rich and Janos, p. 63.)

11 Rich and Janos, pp. 19–27.

Hence, Lockheed possessed not only models that predicted RCS, but also a quantitative tool for designing aircraft with low RCS.[12]

In the summer of 1975, Perko; Robert Moore, who had become Director of TTO; and DARPA Director Heilmeier met to develop a strategy for bringing these technical advances to fruition in a real weapons system. Given the magnitude of the anticipated advances, they decided that a full-scale flight demonstration would be needed to make the results convincing. (The 1971 Air Force prototyping study cited earlier had come to the same conclusion, but not with the same ambitious goal.)[13] Heilmeier insisted that the program could not go forward without Air Force backing. Air Force support was highly uncertain, as the Air Force saw limited value in a stealthy strike aircraft, given the severe operational limitations that would be required to achieve a very low radar cross section. The proposed stealth aircraft would be relatively slow and unmaneuverable, giving it limited air-to-air combat ability, and it would have to fly at night—a far cry from the traditional Air Force strike fighter. There were also competing R&D priorities, most notably the Advanced Combat Fighter program (which eventually became the F-16).[14]

As part of his effort to obtain OSD support for Stealth, Moore went to General John Toomey in Director Defense on Research and Engineering (DDR&E) Organization, who had strong credentials in radar technology. DDR&E Currie was briefed on the concept and supported it.[15] Thanks to Currie's earlier efforts to build relationships with the Service leadership, he was able to discuss the problem directly with General David Jones, the Air Force Chief of Staff, and General Alton Slay, the Air Force R&D Director. Although the Air Force remained skeptical as to a stealth strike fighter's value, Currie and Jones brokered a deal to obtain active Air Force support for the DARPA stealth program—provided that funding for the stealth development would not come out of existing Air Force programs, especially the F-16.[16]

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12 Aronstein and Picacirillo, p. 19.

13 Ibid., p. 11.

14 Moore believes that DARPA should have been prepared to proceed without Air Force agreement: "I knew the Air Force would have to come on board if we were able to fly by a radar undetected." (Interview with Robert Moore, July 30, 2001).

15 Working around the bureaucracy, Moore went back to Myers at DDR&E and suggested that he ask DDR&E Currie to request a briefing on the stealth work. Currie requested the briefing and was very excited about the idea, urging Heilmeier to proceed. (Interview with Robert Moore, 7/30/01.)

16 Interview with Malcolm Currie, June 11, 2001.

Both Lockheed and Northrop presented concepts that were predicted to meet or exceed the signature goals. Both were awarded Phase 1 contracts for 4-month projects that would conclude with model tests and selection of one firm for a Phase 2 award. Early in Phase 1, the program was classified "Top Secret."[17] At the conclusion of Phase 1, both contractors had achieved objectives. Dr. William Perry, who had taken over for Currie, asked the Air Force Tactical Air Command for input. Gen. Bob Dixon and Gen. Larry Welch, based on their experience with the Skunk Works on high-risk, high-classification projects, gave positive feedback. Lockheed won the sole Phase 2 award, and the Tactical Air Command became the key logistical and operations point of contact for the Air Force side of the program.[18] However, DARPA wanted to preserve the expertise that Northrop had developed. It encouraged Northrop to maintain its team, which shortly thereafter engaged in DARPA-sponsored design studies for the Battlefield Surveillance Aircraft, Experimental (BSAX) program. These studies led to the TACIT BLUE program, which, in turn, provided data and technology for the B-2 stealth bomber program,[19] as well as advanced cruise missiles.

The Phase 2 program—HAVE BLUE—began in 1976. HAVE BLUE was a proof-of-concept aircraft designed to test out Lockheed's concepts for "very low-observable" capabilities while meeting a set of realistic operational requirements. Phase 2 was conducted as a classified, Special Access Program managed by a special office within Air Force Systems Command and utilizing special oversight procedures for congressional review. Nonetheless, Lockheed's Skunk Works managed the program in an environment open to experimentation and flexible problem solving, with a high degree of communication among scientists, developers, managers, and users. OSD leadership kept the program focused and moving forward—Phase 2 was deliberately limited to demonstrating that the RCS objectives could be achieved—in the face of many fundamental uncertainties.[20] Two HAVE BLUE demonstrators were contracted. They were kept as small and simple as possible to minimize cost. There was no mission equipment, the cockpit was unpressurized, and the aircraft had no air-to-air refueling capability. Only the second aircraft had radar absorbing material (RAM) coatings. HAVE BLUE was approximately one-quarter scale to the eventual F-117A: 38 feet long,

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17 Gen. Jasper Welch had initially suggested this approach during previous conversations with Moore. (Interview with Robert Moore, 7/30/01.)

18 Rich and Janos, pp. 41–42.

19 Aronstein and Piccirillo, p. 33.

20 Ibid., pp. 60 and 137.

22.5-foot wingspan, 12,500-pound maximum take off weight, 2,850-pound thrust in each of two engines, compared with the F-117A at 66 feet long, 43-foot wingspan, 52,500 pound, and 10,800 pounds of thrust per engine.

The first flight test was 20 months following contract award. Subsequent test flights clearly demonstrated that such planes could attain the very low RCS and perform within the posited specifications. While both aircraft were lost in crashes during the demonstration program—when HAVE BLUE 2 was lost, only two or three planned sorties remained to be flown—they had succeeded in the proof-of-concept of a stealthy aircraft. Concurrent with demonstration that an extremely low RCS was achievable, the Air Force Systems Command conducted studies and demonstrations of the additional technologies that would be needed for such an aircraft to be a mission-capable system. (A 1977–1979 demonstration of a passive infrared fire control system was particularly critical.)

Based on these results, and guided by the high priority of countering Soviet numerical superiority with US technology, as outlined in the Offset Strategy, USD(R&E) Perry sought an accelerated development of a real weapons system. Studies were conducted of alternative concepts for employing a full-scale version of such an aircraft—as a fighter, a bomber, or a surveillance-reconnaissance system. While there were advocates for all these alternatives, its employment as a penetration-fighter was selected as the first development effort. Secretary of Defense Brown agreed to make the development of stealth aircraft "technology limited" as opposed to funding limited. The DARPA stealth program was immediately transitioned to a Service acquisition program (SENIOR TREND) with an aggressive initial operating capability (IOC) of only 4 years—forgoing the normal development and prototyping stage. To obtain the required support from the Air Force, Perry, like Currie before him, worked closely with General David Jones, the Air Force chief of staff, and General Alton Slay, the Air Force R&D Director. The objective was to build and deploy a wing of stealth tactical fighter-bombers (75 planes) as rapidly as possible.[21] Furthermore, in order to obtain the largest possible technical lead, it was deemed necessary to hide the SENIOR TREND acquisition as a highly secret "black" program, similar to HAVE BLUE.[22]

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21 Interview with William Perry, June 6, 2001.

22 This created a complication because the existence of a stealth research program was already in the open. So it was continued as is, with the actual development of a weapon system kept hidden. HAVE BLUE was a black program. (Interview with William Perry, June 6, 2001.)

Perry established efficient and effective stealth program management processes. Changes in mission and redirection of funding are the common issues in the traditional development process, in which a program must regularly defend its budget against other programs and respond to the preferences of members of Congress. These forces were blunted by Perry's hands-on management efforts and the fact that this was a "black" program. Perry chaired special executive review panels, which met every 2 months. He retained decision authority—there was no voting. The Air Force PM was instructed to highlight problems with bureaucratic delays and with technology, which Perry would address personally. (After a few such interventions, there were far fewer bureaucratic obstructions.) Perry created a special umbrella program office that included stealth programs for ships, satellites, helicopters, tanks, reconnaissance aircraft, advanced cruise missiles, Unmanned Aerial Vehicles (UAVs), and strategic bombers, as well as stealth countermeasures.[23] This created a mechanism through which different stealth programs at different stages could experiment with different approaches and learn from each other, as well as maintaining support for the underlying technology base.[24] Because the program was highly classified, special subcommittees of the House and Senate Armed Services Committees were established. Congressional support was secured and maintained through honest communication of both successes and problems. This built trust with the committees, which was indispensable. The counterstealth programs maintained under the umbrella stealth program helped to ensure that the high level of classification did not result in lack of independent review and criticism.

The Air Force supported Lockheed's development of the aircraft, made provisions for an operational wing to be deployed, undertook an extensive testing program, and developed new operational practices to take advantage of the F-117A's special capabilities. Despite a variety of problems discovered during operational testing—such risks, arising from concurrent development due to the accelerated schedule, were understood and accepted and hence did not disrupt the program—the first F-117A was delivered in 1981, and 59 were deployed by 1990.[25] In 1991, the F-117A helped the US achieve early air superiority in Operation Desert Storm in the face of the same type of

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23 Colonel Paul Kaminski eventually became the head of this program office, which helped ensure continuity of development efforts beyond the F-117A. DARPA's TACIT BLUE program for a stealthy reconnaissance aircraft led to the B-2 Stealth Bomber. The Sea Shadow tested stealth concepts on a surface ship for the US Navy (see Chapter II of this volume).

24 Aronstein and Piccirillo, pp. 175–176.

25 Ibid., pp. 108 and 127.

Soviet anti-aircraft systems that had caused so much trouble for US-made tactical aircraft in Vietnam and the Yom Kippur War.

In championing stealth, DARPA harnessed industry and Service lab ideas to pursue a radical new warfighting capability. The notion of low-observable systems had been raised before but had not been pursued in a concerted manner because the Services had little interest in such a radical, non-traditional concept. With high-level support from civilian leadership in different administrations, DARPA overcame that resistance, set out priorities, and obtained funding for the considerable engineering work to develop a proof-of-concept demonstration system. This demonstration enabled top civilian and Service leadership to proceed with confidence. OSD and Service leadership, once persuaded, rose to the challenge, and provided funding and support to implement a full-scale weapons program with limited, achievable objectives. "Despite unforeseen and serious challenges a small team was able to develop a radically new and important weapon system in record time, safely, and without compromising the initial objective."[26] The F-117A was developed and fielded under the highest levels of secrecy, leading to a "secret weapon" capability for several years and giving the US more than a decade advantage over any adversary—exactly what DARPA and top DoD leadership had envisioned.

Indeed, an F-117A was not lost to anti-aircraft fire in combat until March 27, 2001, during Operation Allied Force in Kosovo, 10 years after Desert Storm. The loss is significant. Combined with advancing anti-stealth technology, it portends the end of the unfettered advantage conferred by the F-117A. For instance, after the F-117A was shot down in Kosovo and a second was damaged, Navy EA-6B Prowlers jamming aircraft accompanied all F-117A and B-2 aircraft.[27] Also, rather than confront NATO airpower directly, Serb forces undertook strategies to disrupt operations. They used their weapons sparingly and only when they had a reasonable chance of success, which was enough to keep NATO aircraft above 15,000 feet, where they were ineffective against the targets associated with the ongoing ground operations in Kosovo.[28] On the technology side, a

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26 LTC R. Mosely, "Senior Trend Test Program from Concept to Initial Operational Capability: Planned vs. Actual," briefing dated December 20, 1983, with cover memo from Colonel Michael E. Sexton to Colonel Paul G. Kaminski dated December 21, 1983, as quoted in Aronstein and Piccirillo, p. 111.

27 Scott Truver, "Today Tomorrow and After Next," published at <http://www.navyleague.org/seapower/today_tomorrow_and_after_next.htm>.

28 Earl H. Tilford, Jr., "Operation Allied Force and the Role of Air Power," *Parameters*, Winter 1999–2000, pp. 24–38.

recent report on Chinese military modernization noted efforts to build ultrawideband and bistatic/multistatic radars and to fuse data from networks of sensors in order to reduce the value of stealth aircraft.[29] Samples of the radar-absorbing material from the downed F-117A likely found their way to Russian anti-aircraft design houses. In general, "history tells us that defeated armies learn the lessons of technology better than the victors."[30]

Looking forward, the US military continues to require revolutionary concepts to address the changing threat environment. "The F-117A development is not a pattern for every program but rather a useful example of how a unique technological opportunity can be quickly and effectively exploited to provide a valuable military capability at relatively moderate cost."[31] But the key is to have underlying understanding of strategic challenges so that the potential of new technologies can be recognized and developed into disruptive military capabilities. The task for the US today may be to look beyond the emerging RMA and move in entirely new directions, fostering the next RMA.

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29 Mark A. Stokes, *China's Strategic Modernization: Implications for the United States*, Strategic Studies Institute, US Army War College, September 1999.

30 Neil G. Kacena, *Stealth: An Example of Technology's Role in the American Way of War*, Air War College, Air University, April 14, 1995, p. 86.

31 Aronstein and Piccirillo, p. 194.

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II. DEVELOPING THE NAVY'S 21ST CENTURY SHIPS: DARPA'S ROLE IN FACILITATING NAVAL INNOVATION

Jack Nunn and Alethia Cook

BACKGROUND

With the end of the Cold War the US Navy faced profound changes in the nature of the military threat, in the future peacetime and military operations it might undertake, and ultimately in the naval force structure that would need to be maintained. A 1992 Navy study entitled *...From the Sea: Preparing the Naval Service for the 21st Century* concluded that the new situation was "a marked change from the scope of global conflict envisioned under the Maritime Strategy during the Cold War—a strategy which required independent, 'blue water, open ocean' naval operations on the flanks of the Soviet Union. By restricting enemy access to the open sea, thereby protecting vital sea lines of communication, our naval forces were to provide important but indirect support to the land campaign."[1] In contrast, the post-Cold War world presented sharply different circumstances:

> Today, the absence of a global naval threat has virtually eliminated the need to conduct separate, independent naval operations far at sea. [The] operational focus has shifted to littoral warfare and direct support of ground operations. By exploiting their access to littoral regions, naval forces enable the introduction of heavier follow-on forces from other services.

Littoral warfare in direct support of ground fighting brings naval forces squarely into the joint warfighting arena. *From the Sea* clearly states that Joint Operations—or "Jointness"—is an essential element of every military operation:

> Naval Operations in littoral regions transform the classic Air-Land battle into a Sea-Air-Land-Space battle. This confluence of complex environmental and warfighting challenges demands specialized warfare skills, available only through a completely integrated joint force.[2]

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1 US Department of the Navy, *...From the Sea: Preparing the Naval Service for the 21st Century* (Washington DC: Pentagon) September 1992. *From the Sea* was a White Paper signed jointly by the Secretary of the Navy, the Chief of Naval Operations, and the Commandant of the Marine Corps and widely quoted in subsequent discussions of Navy strategy.

2 Ibid.

The Sea-Air-Land-Space battle concept represented a doctrine distinct from that employed for the Navy's Cold War missions. *From the Sea* emphasized more versatility in sea operations combined with the ability to project maritime power ashore, returning to an expeditionary role for both the Navy and Marine Corps. In addition to this change in strategic threat, it also acknowledged significant changes in the technology that might be exploited to meet future threats. The combination of new technologies and new operational concepts for exploiting them represent the Navy's role in the emerging Revolution in Military Affairs (RMA).

From the Sea postulated four key operational capabilities necessary to achieve the Navy's national security mission in this new era: command, control, and surveillance; battlespace dominance; power projection; and force sustainment.[3] Attaining these operational capabilities required the exploitation of the new technological developments through sophisticated systems integration:

> …surveillance efforts will continue to emphasize exploitation of space and electronic warfare systems to provide commanders with immediate information, while denying and/or managing the data available to our enemies. Integrated information and netted sensors will allow [the Navy] to use surveillance data from all sources—national and combined—and to target and strike from a variety of land, sea, and air platforms.
>
> …Battlespace dominance means that we can maintain access from the sea to permit the effective entry of equipment and resupply…Naval Forces must also have the capability to deny access to a regional adversary, interdict the adversary's movement of supplies by sea, and control the local sea and air…
>
> Power projection from the sea means bombs, missiles, shells, bullets, and bayonets. When Marines go ashore, naval aviation aboard aircraft carriers and—if required—land based expeditionary aircraft will provide them sustained, high-volume tactical air support ashore to extend the landward reach of our littoral operations…[4]

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3 Ibid.

4 Ibid.

DARPA'S ROLE

The Defense Advanced Research Projects Agency (DARPA) was involved in several efforts since the 1970s to better understand the interrelationship between technology and future operational capability, including new surface ship concepts. Elements within the Navy had been considering fundamental changes to ships for several years, but there was strong resistance to change. Even incremental introduction of new technology into the surface Navy has been difficult. Contractors have long complained that "nothing can be used on a new Navy ship that has not been certified, and nothing can be certified until it has been used on a Navy ship."[5] DARPA, as an outside organization, played an important role in testing new ideas and ultimately helped to incorporate new technologies into surface vessels.

Starting in the late 1970s, the Navy undertook several major surface ship developments that involved DARPA, or DARPA-developed technology, new operating concepts and new acquisition methods designed to encourage commercial firms to participate and stimulate innovation. These development efforts—in areas such as stealth, automation, and target acquisition and attack technologies—have been incorporated into today's Navy's Surface Combatant for the 21st Century (SC 21) development effort,[6] but no ship embodying the full range of these technologies and concepts has actually been deployed. The initial efforts to develop new capabilities were insufficiently funded and terminated short of full deployment. Sea Shadow, the first ship development effort in this series, was deactivated after initial testing but has since been used from time to time as a technology demonstrator. The Arsenal Ship was terminated by the Navy prior to any serious demonstration effort. Technologies and concepts developed for Sea Shadow and Arsenal Ship were transferred to the DD-21, the third effort. The DD-21, now termed DD(X), is currently under consideration for development and deployment. (See Table II-1.)

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5 Based on authors' interviews with Navy pump and small motors suppliers during research on the defense technology and industrial base in 1993.

6 The Joint Requirements Oversight Council approved the Twenty-First Century Surface Combatant (SC 21) Mission Need Statement (MNS) in September 1994. The MNS's required capabilities included: Power Projection; Battlespace Dominance; Command, Control and Surveillance; Joint Force Sustainment; Non-combat Operations; and Survivability / Mobility. The Defense Acquisition Board (DAB) gave approval to Milestone 0 for SC 21 Acquisition Phase 0 (Concept Exploration and Definition) in January 1995. SC 21 was to include a family of new ships. The first was the DD-21, a destroyer with both land attack and maritime dominance capabilities. The Navy planned to acquire 32 DD-21s, <http://www.fas.org/man/dod-101/sys/ship/dd-21.htm>.

Table II-1. Comparison of Surface Ship Concepts

Characteristic	Sea Shadow	Arsenal Ship	DD-21
Power Plant	Diesel electric	Electric or auxiliary power	Integrated power system
Available Design Details	SWATH (Small Water Plane Area Twin Hull) Length, 164 feet; Beam, 68 feet; Draft, 14.5 feet; Displacement, 560 tons; Crew, 10	Low radar signature (stealthy); double hull; size between 500–800 feet; Crew, 0–50; highly automated; may be remote controlled	Low radar and acoustical signatures, highly survivable, improved targeting, delivers high rate of fire up to 100 miles inland; Crew, 95–150
Purpose	Technology demonstration platform	Platform for 500-cell Vertical Launch System	Land attack support for ground forces
Status	Reactivated in 1999 as a DD-21 technology test platform	Terminated	Under development
Start Date	Early-1980s	1995	Contract award for the first ship FY 2005, delivery anticipated 2010
Terminal Date	Placed in dry dock in 1994, reactivated 1999	Funding terminated in FY 1998 budget	NA

Sources:

Sea Shadow, US Navy, "Fact File," Downloaded from <http://www.chinfo.navy.mil/navpalib/factfile/ships/ship-sea.html> on 10/1/01.

The Center for Defense Information, "Arsenal Ship," Downloaded from <http://www.cdi.org/issues/naval/arsenal.html>.

Sea Shadow

Sea Shadow focused on evaluating stealth technology on surface vessels. It also served as a platform for the integration and evaluation of other new technologies, including ship control systems, structures, automation for reduced manning, sea keeping, and signature control.[7] The focus on stealth technology made Sea Shadow a highly classified program managed by DARPA, the Navy, and Lockheed Martin Missiles and Space Company.

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[7] *Sea Shadow*, US Navy, "Fact File," <http://www.chinfo.navy.mil/navpalib/factfile/ships/ship-sea.html>.

Development Chronology

The idea for a stealthy naval surface vessel occurred to Ben Rich in 1978, when he was Director of the Lockheed Skunk Works. The project photographer working on the model for the first stealth aircraft complained about defects in a recently purchased Polaroid camera. Rich wrote that the photographer told him:

> I've been taking instant view shorts of the stealth model, and I'm getting very fuzzy pictures. I think I've got a defective lens," he remarked. I [Rich] slapped my head, knowing we had accidentally stumbled onto an exciting development. "Time out! There isn't a damn thing wrong with your new camera," I insisted. "Polaroid uses a sound echo device like sonar to focus, and you are getting fuzzy pictures because our stealthy coatings and shaping on that model are interfering with the sound echo.[8]

The Skunk Works immediately began investigating stealthy submarines undetectable to sonar. They purchased a small model submarine, put faceted fairings on it, and tested it in a sonic chamber. These changes reduced the sonar return from the model sub by three orders of magnitude, a result that Rich termed "as rare an occurrence as an astronomer discovering a new constellation." [9] Lockheed designed a stealthy sub with the traditional cigar-shaped hull "shielded by an outer wall of flat, angular surfaces that would bounce sonar signals away and also muffle the engine sounds and the internal noises of crewmen inside the vessel." After running acoustical tests Rich took the results to the Navy submarine R&D office, where they were rejected.

Lockheed's involvement in Navy stealth might have stopped there had it not been for a company engineer just back from a Pearl Harbor business trip who mentioned to Rich that he had seen a catamaran-type ship that the Navy had built experimentally. This prototype SWATH (Small Water Area Twin Hull) ship was proving to be amazingly stable in heavy seas and was considerably faster than a conventional ship. Rich felt that a catamaran SWATH ship held real promise as a model for a stealthy surface ship, so he presented the idea Dr. William Perry, the Under Secretary of Defense for Research and Engineering. Rich suggested they could test several stealth-related technologies on the ship. Dr. Perry agreed and arranged for DARPA to issue a study contract.[10] This small contract was aimed at developing a workable model catamaran and testing it against

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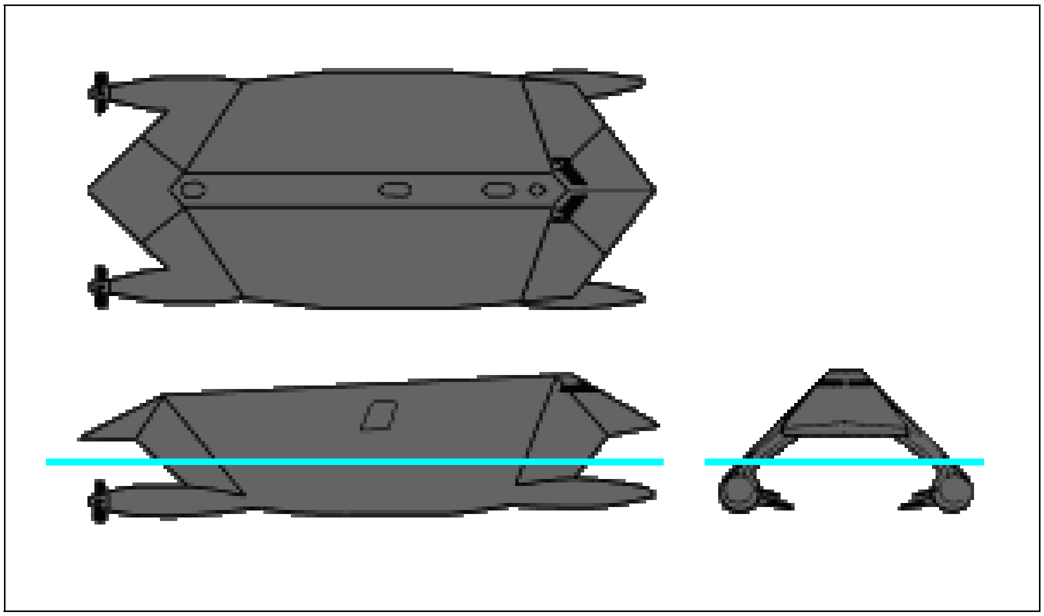
8 Ben R. Rich and Leo Janos, *Skunk Works*, Boston: Little, Brown and Company, 1994, p. 271.

9 Ibid., pp. 271–272.

10 Ibid., p. 273.

Soviet X-band radar. Rich wrote, "Shape was the key to defeating Soviet radar. Coatings accounted for only 10 percent effectiveness in deflecting radar. The rest was quietness of a vessel's engines and minimizing its wake."[11] The Lockheed team developed a model with a pair of underwater pontoon-type hulls that propelled the ship with twin screws. It had good stability in rolling seas and produced very little wake.

The subsequent prototype resembled the F-117A stealth fighter (see Chapter I) with a series of severe flat planes at 45-degree angles. "Diesel-electric propulsion would power the ship's counter-rotating propellers. Careful shaping of the pontoons and the propellers cut down sharply on noise and wake."[12] In addition to stealth design structure, Sea Shadow had an "A-frame" design to reduce the surface area of the ship coming in contact with the water in an effort to reduce the ship's signature. The SWATH configuration incorporated two submerged pontoons that supported the upper structures while increasing ship stability. It also minimized the ship signature through the sloped design of the hull.



Sources:
Federation of American Scientists. "Military Analysis Network, US Navy Ships—Sea Shadow," downloaded from <http://www.fas.org/man/dod-101/sys/ship/sea_shadow.htm> on 10/1/01.

Figure II-1. Sea Shadow Schematic

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11 Ibid.

12 Ibid., p. 274.

The Sea Shadow concept was focused on the Soviet Blue Water threat—specifically the Soviet long-range fighter-bombers that were threatening the US Navy with new look-down, shoot-down radar-guided missiles. The Navy's Aegis missile frigate was being procured with the objective of destroying incoming cruise missiles. Lockheed argued that its ship would cost only $200 million (compared with the billion dollar Aegis frigate), would be armed with Patriot-type missiles that could attack the cruise missile carrying bombers, and would be invisible to the Soviet radars. The ship "could be sent out hundreds of miles ahead of the carrier task force to shoot down the Soviet attack aircraft before they got within missile range of the fleet."[13]

On reviewing the test data, Dr. Perry ordered the Navy to fund R&D of a stealth ship. Perry was adamant about proceeding although the Navy was highly resistant. In a meeting with the Chief of Naval Operations he responded to the Navy's reluctance: "Admiral, we are going to build this ship; the only question is whether the Navy is going to be part of it."[14] Perry tried to soften the blow by stating that the funding would not come out of other Navy ships.

The Sea Shadow was constructed in modules in several shipyards and then assembled inside a huge submergible barge. It was made of very strong welded steel, displaced 560 tons, and was 70 feet wide. The ship had a four-man crew—commander, helmsman, navigator, and engineer.[15] These figures went up over time and subsequent tests carried up to 24 people—still far less than on normal Navy craft.[16]

A number of impediments to development were reported. Many of these appear to have been bureaucratic. In his book, Rich is scathing in his evaluation of both Navy resistance to new concepts as well as the approach of Lockheed's own shipbuilders. In recent interviews, Ugo Coty, the chief Skunk Works designer of the Navy stealth concept, reported that he had shared many of Rich's concerns about the development project. Coty said that a major problem is that the Navy "never builds experimental ships."[17] Instead, the Service builds the first ship of a class of ships—and may not build the rest of the class. Thus the people Rich had called "bureaucrats and paper pushers" in his book,

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13 Rich and Janos, p. 274.

14 Interviews with William Perry (June 6, 2001) and Robert Fossum (February 7, 2002).

15 Rich and Janos, p. 277.

16 Paul A. Chalterton and Richard Paquette, "The Sea Shadow," *Naval Engineers Journal*, May 1994, pp. 296–308.

17 Interview with Ugo Coty, December 1, 2001.

were simply a typical part of a standard shipbuilding program, and to them the demand for paint lockers (on a ship that would not be regularly chipped and painted) made perfect sense.

Once constructed, the Sea Shadow was towed to Long Beach to begin its tests off Santa Cruz Island. All tests were at night against the most advanced Navy hunter planes. Rich reports that tests were extremely successful:

> One typical night of testing, the Navy sub-hunter airplanes made fifty-seven passes at us and detected the ship only twice—both times at a mile-and-a-half distance, so that we would have shot them down easily long before they spotted us. Several times, we actually provided the exact location to the pilots and they still could not pick us up on their radar.[18]

The tests continued over 2 years. All reports indicate that the Sea Shadow performed well.[19] Nevertheless, although individual technologies were applied to Navy ships, the ship itself was never introduced into the fleet. Rich's view was that the admirals who ran the surface fleet were against it. He wrote that they told him the design was too radical. They told him, "If the shape is so revolutionary and secret, how could we ever use it without hundreds of sailors seeing it? It's just too far out." He noted, "Although the Navy did apply our technology to lower the radar cross section of their new class of destroyers, we were drydocked before we had really got launched."[20]

When Dr. Perry left office, the next administration's OSD Comptroller reduced funding for the DD-51 in the following year's budget request, which the Navy interpreted as redirecting funds to pay for Sea Shadow. In response, Chief of Naval Operations Admiral Hayward cut the program out of the budget. Coty went to Hayward and asked why and was told it was because the Navy Program Manager was asking for too much money. The PM had submitted a request for missile development to arm the new ships and everything to go with them. In Hayward's view these requirements had come "before the ship had even been shown to be stealthy."[21] Coty said that after a fast reeducation of the new Administration, money was restored. But stealth supporters such as Rich and Coty believed the Navy brass largely disapproved of the development.

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[18] Rich and Janos, p. 279.

[19] Ibid., see Chalterton and Paquette for a more restrained but still supportive view.

[20] Rich and Janos, p. 278.

[21] Ibid.

Sea Shadow was deactivated from 1987 until 1993, when it was reactivated for additional equipment testing. In 1993 and 1994, it was openly tested, serving as a platform for testing several concepts including combat systems developed by Lockheed under contract with DARPA. Two Combat System prototypes, the Automated Combat Identification System (ACIDS) and the Tactical Action Advisor (TAA), were tested. The ACIDS was a decision aid to automatically identify air and surface tracks based on sensor and intelligence information as defined by the tactical operators. The TAA system was a decision aid to support a Tactical Action Officer or Warfare Commander. The testing and demonstration of both the ACIDS and TAA prototypes were a part of the DARPA-funded High Performance Distributed Experiment (HiPer-D) program, and the versions of the ACIDS and TAA prototypes that were tested used software technology funded by DARPA for civilian and defense applications.[22] The testing was again reported to be successful.

According to Lockheed representatives, the tests also proved out the use of commercial-off-the-shelf (COTS) technology in the systems and were the basis for using COTS in the Aegis system. As a result, each of the developed Aegis employed more COTS in its computer hardware and software, and the Aegis 71 is now fully COTS.[23]

The Sea Shadow was once again placed in lay-up status in 1994. Although it did not enter the fleet, its design did contribute to follow-on programs like the Arsenal Ship and the DD-21 as well as other ships. The ship was reactivated in 1999 in anticipation of using it to test new technologies being developed for the DD-21.[24] Specifically, the Navy said that the Sea Shadow would help support risk reduction efforts for the DD-21 and other future ships and facilitate the testing of automation systems and information technologies that are key to reducing manning and increasing ship survivability.[25] Tests have focused on design concepts for the destroyer. The Sea Shadow continues to be used to test DARPA concepts, including a platform for DARPA's High-Performance Distributed Computing experiment.[26]

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22 Gerard J. Mayer, "Aboard the Sea Shadow, Lockheed Martin Advanced Technologies," <http://www.atl.external.lmco.com/overview/papers/SEASHADOW.html>.

23 Interview with Mr. Gerard Mayer, Lockheed Martin, November 29, 2001.

24 "Sea Shadow". Military Analysis Network, US Navy Ships—. Federation of American Scientists, <http://www.fas.org/man/dod-101/sys/ship/sea_shadow.htm> on 10/1/01.

25 "Sea Shadow Reactivated for Technology Testing of Future Surface Ships," *Navy Wire Service,* March 18, 1999.

26 Mayer, "Aboard the Sea Shadow."

Sea Shadow Technology and Acquisition Innovations

Following are some of the processes/technologies tested on Sea Shadow:

- Command and Control
  - Improved ship control
  - Automated ship control
  - The Communicator
- Materials and Structures
  - Structural design for reduced signature angled surfaces, rounded edges, and a single, lightweight mast
  - Advanced structures
  - Twin hull construction employing a unique hull design with two thin struts to support the deck structure and two submerged, submarine-like pontoons known as the Small Water Plane Area Twin Hull (SWATH)
- Propulsion
  - Jet, counter-rotating engines (jet not installed, used diesel instead, but proved stealth principal of the counter-rotating engines)
- Sustainment
  - Automation for reduced manning
- Weapons
  - Automated Combat Identification System (ACIDS)
  - Tactical Action Advisor (TAA)

Several key technologies related to sea-based stealth were developed and demonstrated, as was SWATH technology; new communication, command and control approaches; and automation for reduced manning. From all evidence, the stealth component worked very well. This was apparent in the early 1980s, but only slowly penetrated the Navy leadership. Reduced manning was also fully demonstrated. However, such reductions continued to be opposed by many among the uniformed Navy leadership who worried about the ability to respond to battle damage with much reduced crews.[27]

Summary

Overall Sea Shadow has proven to be a very valuable test vessel. DARPA played a significant role in its funding and development. The Program demonstrated many of the

[27] Interview with John Douglass, February 5, 2002.

problems that are likely to occur when DARPA works with the Services to introduce novel technologies that might have significant impact on the Services' force structure and operations. The stealthy Sea Shadow immediately came into competition with other Service priorities (Aegis). It had no powerful Navy advocate. It ran up against an acquisition process that made it difficult to succeed (e.g., Was it the lead ship of a new class rather than a demonstrator?). And, with Dr. Perry gone, it had no powerful advocate anywhere in the DoD. It sank into the background. Still, it is possible to track technologies developed here to the ill-fated Arsenal Ship, the current DD-21 and today's DD(X).

Arsenal Ship

Whereas the Sea Shadow development was intended to help defend the US fleet on the high seas against the Soviet navy, the Arsenal Ship development was directed at supporting the Navy's new post-Cold War concept of littoral conflict. "The basic requirement for the Arsenal Ship, established in a joint Navy-DARPA Memorandum on March 18, 1996, was to satisfy joint naval expeditionary force warfighting requirements in regional conflicts by providing the theater commander with massive firepower, long-range strike, and flexible targeting and possible theater defense through the availability of hundreds of vertical launch system (VLS) cells."[28]

A number of studies had suggested the concept. According to a RAND Acquisition Process report written at the time, the concept was derived from several studies addressing the future Navy contribution "to the conduct of land-based warfighting capabilities, especially in providing artillery-like fire support to lightly armored Army and Marine forces."[29] The concept was viewed as "consistent with the Defense Science Board (DSB) Summer Study, *Tactics and Technology for 21st Century Military Superiority*, published in October 1996; the *Army's long-term* vision as outlined in *Army After Next*; and the Marine Corps' philosophical commitment to innovative change as embodied in *Sea Dragon*."[30] Two Navy studies examined the concept just prior to its formal initiation. An internal Navy study conducted by the Office of Naval Research considered the concept for a "missile barge" in the spring of 1995 and the Naval Surface

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28 Charles S. Hamilton, *Arsenal Ship Lessons Learne*d*,* Arsenal Ship Joint Program Office, December 31, 1997, p. 1.

29 Robert S. Leonard with Jeffrey A. Drezner and Geoffrey Sommer, *The Arsenal Ship Acquisition Process Experience,* Santa Monica: The Rand Corporation, 1999, p. 97.

30 Ibid.

Warfare Center considered the feasibility of combat systems later that summer.[31] All these efforts envisioned a changed world from the Cold War.

However, despite the changed mission from Sea Shadow, there were many commonalities among the technologies investigated and with the development approach for the two vessels. Admiral Charles Hamilton, who as a Captain was the Program Manager of the Arsenal Ship, indicated that the technology for the program was well informed by the earlier development of Sea Shadow.[32] Commonalities included testing technologies designed for reduced crewing, low radar signature, and reduced unit costs.

The Arsenal Ship was to be a floating weapons platform for projecting naval power ashore. A forward observer located somewhere onshore could call in the fire, select the type munitions (missile or gun), and direct it on the target from his location.[33] This concept promised to provide more timely and accurate fire support ashore. Proponents argued:

> The pre-positioned ships would provide the unified commanders in chief (CinCs) with massive firepower in the early hours of a conflict-much sooner than could be provided by bombers traveling from the continental United States or from aircraft carriers, unless they happened to be nearby during a crisis.[34]

The Arsenal Ship concept threatened the almost exclusive role that naval aviation played in many early shore engagements as well as the role that the Air Force bombers were carving out for themselves in the post-Cold War period (e.g., Global Reach). Hence, it was viewed as competition for both Navy carrier aviation and the Air Force's B2 bomber.[35] The Program's estimated costs also put it in competition with the DD-21. Hence, it had only mixed support among the top echelon of the uniformed Navy.

The Arsenal Ship concept had the support of both the Chief of Naval Operations, Admiral Jeremy Boorda (who was not an aviator), and the Assistant Secretary of the Navy for Research, Development and Acquisition, Mr. John Douglass, who earlier as an Air Force Officer had headed that Service's Precision Guided Munitions Office. When

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31 Ibid.

32 Interview with Admiral Charles Hamilton, January 22, 2002.

33 Douglass interview.

34 Katherine McIntire Peters, "Ship Shape," *Government Executive,* August 1, 1997. Also see Lt. Dawn Driesbach, USN, *The Arsenal Ship and the US Navy: A Revolution in Military Affairs Perspective,* Monterey, CA: Naval Postgraduate School.

35 Ibid.

Admiral Boorda and Mr. Douglass decided to launch the development, they sought to include DARPA to help implement it, as well as a complementary source of research and funding.[36] The DARPA Director, Larry Lynn, was intrigued by the possibility that the ship, having a very small crew or perhaps none, might be built so as to be virtually unsinkable. He approved DARPA taking on the program although he was concerned with the Navy's poor record in implementing new technology developed in the past with DARPA. He was not optimistic that the Navy would implement an idea as radical as Arsenal Ship. After further discussions, however, DARPA did become involved and a Memorandum of Agreement (MOA) was signed (Attachment A).[37]

The MOA laid out the technological and acquisition objectives of the program, as dictated by the operational concepts for the ship. The ship would be designed to deliver large amounts of munitions to a Ground Commander early in an engagement. It would therefore be forward deployed much of the time and under control of the Theater Commander. Major goals of the Arsenal Ship development program included:

- Flexible support of ground forces which drove secure communications, reliable data linkage, and a Cooperative Engagement Capability (CEC) for the remote targeting and launch system
- Rapid and sustained support which drove the number of weapons onboard
- Forward basing, which drove reduced manning requirements and survivability concerns including low radar signature and defense against sinking (size of ship or double hull design)

The Program also wanted to test a streamlined acquisition process. Here the objectives included:

- Significantly compressed development timeline—from concept design through fabrication in just 5 years and
- A fixed unit sail away cost of $450 million with a life-cycle cost less than one-half that of a traditional surface ship.[38]

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36 Douglass interview.

37 Larry Lynn, private correspondence, June 2002.

38 Compiled from: Alan Abramson, *The Arsenal Ship Measures Up to Joint Vision 2010,* Newport, RI: Naval War College, November 1997; "Arsenal Ship," Military Analysis Network, US Navy Ships—, Federation of American Scientists, downloaded from <http://www.fas.org/man/dod-101/sys/ship/arsenal_ship.htm> on 10/1/01; and The Center for Defense Information, "Arsenal Ship," Downloaded from <http://www.cdi.org/issues/naval/arsenal.html> on 10/1/01. Also see Leonard, *The Arsenal Ship Acquisition Process.*

The demonstration program was required to show that production ships of this class could operate on a 90-day mission, had the communications and data links necessary for the CONOPS, could salvo 3 Tomahawk missiles in 3 minutes, fire a single Standard Missile (SM2) using the Arsenal Ship as a remote magazine for a Cooperative Engagement Capability, and single launches of the Tomahawk remotely and a single weapon using "digital call for fire."[39] The MOA noted that the missile packages did not necessarily exist so that some of the "proof" would have to be through exercising data links. These links were a critical part of the demonstration. As already noted, the ship's concept pared down on-board systems and directed the effort toward the prime function of transporting and launching massive numbers of munitions (specifically Tomahawk Land Attack Missiles or perhaps a Navy version of the Army Tactical Missile System) against inland targets. There were to be no elaborate surveillance and fire control sensors on the Arsenal Ship system. Rather, the ship would use secure, sophisticated data links to utilize information first from JSTARS or AWACS and later from ground observers. "This concept allows for remote missile selection, on-board missile initialization and remote launch orders, and provides remote 'missile away' messages to the control platform."[40] These were some of the same data issues that had been confronted earlier in the Sea Shadow. DARPA had developed these communications and data systems through its Common Data Link efforts that were applicable to both Sea Shadow and its Unmanned Aerial Vehicles efforts.

A small crew size (0–50 members) was essential in order to minimize operations costs for the ship since manning reportedly accounts for approximately 40% to 60% of the total life-cycle costs of a typical surface ship. Automation and the potential for smaller crews had been investigated in the Sea Shadow trials. Many of the ideas on crew reduction for the Arsenal Ship appear to have been an outgrowth of the Navy's "Smart Ship" Project established in 1995 and ongoing during the period of the Arsenal Ship. The Smart Ship Project was initiated as a result of a report by the Naval Research Advisory Committee's (NRAC) panel on Reduced Manning. Its objective was to reduce crew size and workload through the implementation of mature technologies, as well as changes in policies and procedures.[41] The Arsenal Ship planned to reduce its crew complement

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39 "Arsenal Ship Lessons Learned Report," Tab B, <http://www.fas.org/man/dod-01/sys/ship/docs/arsenal/sec1.html>.

40 "Arsenal Ship," The Center for Defense Information.

41 Leonard et al., *The Arsenal Ship: Acquisition Process Experience*, MR-1030-DARPA, Appendix A, p. 98.

"through systems automation, utilization of capabilities indigenous to other fleet assets, and a low maintenance design emphasis for the hull as well as shipboard systems."[42] However, crew reduction proved difficult. There were concerns about arrangements to carry out everyday tasks like cooking, cleaning, and systems maintenance. Automation of many of the on-board tasks was a possible answer, but this raised significant technology and operational challenges. One of the greatest concerns among senior Navy personnel was damage control and whether reduced crews could save a damaged ship.[43]

As for munitions, at the time of the Arsenal Ship development, Lockheed was the sole-source developer, manufacturer, and provider for the Navy of the MK 41 Vertical Launch System (VLS), the only operational VLS that would accommodate all the munitions expected to be used by the Arsenal Ship. Early in Phase I, Lockheed offered the system to all of the Arsenal Ship competitors, but the offer price was more than 30 percent of the Arsenal Ship's cost goal. Moreover, this price quote included neither Lockheed Martin's Launch Control System (LCS), which was the only LCS that was weapons-certified for use with the MK 41 VLS, nor updated technical manuals for the MK 41 system. The complete cost of the MK 41 VLS for earlier use (e.g., the procurement and installation price in 1994 for a 64-cell system) was $26.3M, which equals about $29M in FY 1998 dollars—$232M for the anticipated 512-cell Arsenal Ship.[44] By the end of Phase II, all three of the teams (including the Lockheed team) had decided to design their own new VLS systems.

Arsenal Ship was set up under DARPA management as the Arsenal Ship Joint Program Office (ASJPO). This early DARPA lead would "take advantage of the Agency's Section 845, Other Transaction Authority (OTA), and help to facilitate transfer of its innovative business practices to the Navy acquisition community."[45] The program was to transition to Navy leadership at a later phase. The use of Other Transaction Authority allowed the use of relatively few, broad performance characteristics and the assignment of full design responsibility to the competing contractor teams. Technically, the Arsenal Ship was required to use stealth technology, but other than that mandate, contractors could use any approach to meet the other broad operational requirements.[46]

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42 Leonard et al., *The Arsenal Ship: Acquisition Process Experience*, Appendix A, p. 99.

43 Douglass interview.

44 Leonard et al., *The Arsenal Ship: Acquisition Process Experience*, p. 61.

45 Hamilton, "Arsenal Ship Lessons Learned Report," Section 1.2.

46 Charles Hamilton interview.

There was also more industry investment in the project in the form of cost-sharing. This approach changed the traditional contracting management relationship and placed more risk on contractors.

The use of limited performance requirements and the assignment of additional responsibility to industrial design teams made it possible both to limit the size of the program office (initially to two people each from DARPA, NAVSEA, and ONR and growing to three from each organization) and to develop a design that could accommodate the affordability constraints in the project.[47] A Steering Committee was established composed of DARPA and Navy personnel, as follows:[48]

- Director, TTO—DARPA Chairman
- Deputy Assistant Secretary of the Navy (DASN, Ships)
- Assistant Director, TTO for Maritime Programs—DARPA
- Director, Surface Warfare Plans/Programs/Requirements Branch—OPNAV (N863)
- PEO for Surface Combatants
- Office of Naval Research (ONR33)

The Program Manager was responsible for developing a program plan including major decision milestones, and for the development of a program transition plan. The Steering Committee approved the initial program plan, conducted quarterly reviews to assess progress, and provided guidance to the PM. An Executive Committee was responsible for reviewing the program at major decision milestones, evaluating the validity of program cost thresholds, and providing redirection as necessary. The committee members were as follows:[49]

Executive Committee

- Assistant Secretary of the Navy (RD&A)
- Director of Surface Warfare (N86)
- Director, DARPA
- Commander, NAVSEA
- Chief of Naval Research

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47 Leonard et al., *The Arsenal Ship: Acquisition Process Experience*, pp. 26–28.

48 Hamilton, *Arsenal Ship Lessons Learned Report*, Section 1.2.

49 Ibid.

The project was to be undertaken in several phases. The Phase I Solicitation was termed a "radical departure from a traditional DoD Request for Proposal (RFP), in that 'offerors are requested to propose their own unique program approach which will best satisfy the Department of Defense's objectives.' Also, each offeror was asked to propose an Agreement for evaluation, rather than the government specifying a contract to be negotiated."[50] Six industry teams were each awarded $1 million contracts to generate Arsenal Ship Concept Designs and proposals for Phase II. The Phase I funding was awarded by DARPA in July 1996. Phase II contractors were selected in January 1997. The teams were a mix of old line Navy shipbuilders and newer entry defense firms with more electronic and weapons experience. The teams were:

- General Dynamics, Marine/Bath Iron Works, General Dynamics Marine/Electric Boat, Raytheon Electronic Systems, and Science Applications International Corporation
- Lockheed Martin-Government Electronic Systems, Litton Industries/Ingalls Shipbuilding, and Newport News Shipbuilding
- Northrop Grumman Corporation, National Steel and Shipbuilding Co., Vitro Corp., Solipsys, and Band Lavis & Associates, Inc.[51]

Once a selection among the three teams had been made, the winning team was to complete a detailed design of their proposed ship. Phase IV would consist of performance testing and evaluation, and Phase V would have been the production phase. However, with the untimely death of Admiral Boorda on May 16, 1996, Arsenal Ship lost a strong advocate. Three months after the Phase II selection, the Navy informally announced a change in focus for the program (at a meeting with Navy industry) and designated it the Maritime Fire Support Demonstrator (MFSD). This change shifted the Arsenal Ship's role to that of a demonstrator for risk reduction for the SC 21 program:

> ASJPO formally notified the contractor teams that same week, but the form of its notification did not reflect the magnitude of the reorientation. The letter stated, "The Navy is planning on using the Arsenal Ship Demonstrator, in parallel with its primary tests to evaluate the military utility of the Arsenal Ship, to evaluate various SC 21 technologies." The letter went on to state that the "testing can be accommodated within current demonstrator designs." It then provided a list of SC 21 technologies envisioned to reduce risk via sea testing on the demonstrator.

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50 Leonard et al., *The Arsenal Ship: Acquisition Process Experience*, p. 8.

51 Federation of American Scientists, "Military Analysis Network, US Navy Ships—Arsenal Ship," downloaded from <http://www.fas.org/man/dod-101/sys/ship/arsenal_ship.htm>.

> The ASJPO viewed the motivation behind the change as the need to justify research and development funding with greater return on investment. It felt that Arsenal Ship technologies demonstrated through the MFSD were intended to support not just the SC 21 program, but the CVX 5 as well.[52]

With the loss of top naval support, and with the Navy's shift in program focus, Congress cut the program's funding.[53] The Secretary of the Navy announced on October 24, 1997, that the Arsenal Ship program was canceled.[54] In an October 30, 1997, letter to the program's three contractors, DARPA Director Lynn stated "the program was canceled as a result of a lack of funding in FY 1998, which was a direct result of the Navy's poorly articulated and ambiguous legislative strategy for the Demonstrator."[55] Nonetheless, many of the technologies developed for Sea Shadow and Arsenal Ship—stealth, automation to reduce manning, robust data links, and new propulsion systems—were incorporated into the DD-21 and SC-21 programs.[56] Arsenal Ship PM Captain (later Admiral) Hamilton was selected to move to the DD-21 Program from Arsenal Ship.

The program cancellation hurt the contractors, who had been cost-sharing in the project under Section 845 Other Transaction Authority contracts. Also, because Arsenal Ship was not a Navy-run Program during Phases I and II, Navy R&D Centers and participating managers, (PARMs—the people responsible for buying the subsystems for ships), made little effort to respond to contractor calls for information. Both organizations reportedly responded better in Phase II, after the Joint Program Office made money available to the Navy organizations to pay for response efforts.[57] However, the situation raises a question about the ability of DARPA to work with and efficiently manage such a joint program. It illustrates the dilemma between trying to introduce new technology that might negate some of the technology in these Centers and PARMs and

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52 Leonard et al., *The Arsenal Ship: Acquisition Process Experience*, pp. 69–70.

53 Members of the House Armed Services Committee were not persuaded about the requirement for Arsenal Ship and questioned its cost and performance compared with alternative ways to meet the requirement. They also objected to the acquisition plan that gave the Navy an option to enter fixed-price production with the winning design contractor. (Personal correspondence from Jean Reed, former DARPA PM and House Armed Service Committee staff member, January 3, 2003.) The Navy's lack of support after Boorda's death was partially the result of concerns that these few ships with massive missile fire power would be too vulnerable.

54 Department of the Navy, Office of Legislative Affairs, Memorandum for Interested Members of Congress, Subj: Maritime Fire Support Demonstrator (MFSD), October 24, 1997.

55 Leonard et al., *The Arsenal Ship: Acquisition Process Experience*, p. 84.

56 Interview with Admiral Charles Hamilton, January 22, 2002.

57 Leonard et al., *The Arsenal Ship: Acquisition Process Experience*, Chapter 6 and Hamilton, *Arsenal Ship Lessons Learned.*

the need to work with these organizations to gain access to the considerable technologies in them that are still useful.

Inadequate funding was a major factor in the cancellation of Arsenal Ship. The Memorandum of Agreement between the Navy and DARPA included the funding profile shown in Table II-2 below.

Table II-2. Arsenal Ship MOA Funding
($ Million)

	FY 1996	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001
Navy	$4.0	$25.0	$141.0	$90.0	$80.0	$10.0
DARPA	$1.0	$15.0	$47.0	$50.0	$36.0	$21.0

Some contend that the effort was underfunded from the start, and that the underfunding was at least partly the result of staff errors—the use of a DD 51 as a test vessel was initially requested, but that request was left out of the memo reviewed and signed by senior Navy officials.[58] DARPA reportedly tried to make up some of the funds, but could not cover the costs.[59] Some program critics argued that although the cost of each Arsenal Ship had been set at about $450 million, the actual cost of a fully functional, totally loaded Arsenal Ship would be considerably more, with a total magazine cost of about $400 million. In their view the funding was totally inadequate. Other reports put the cost of arming an Arsenal Ship even higher. The New York Times reported that the missiles would cost between $500,000 and $1.5 million apiece, resulting in a total $2 billion in weapons.[60]

Then Assistant Secretary Douglass does not believe that the project was initially underfunded—simply undersupported by the Navy, particularly by the new CNO, in the budget battles. In an interview, he related his total surprise at the time that Admiral Johnson had "given up the Arsenal Ship."[61] He reported that once that action was taken, the program's critics in the Congress killed the program. In fact, the costs of

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58 Leonard et al., *The Arsenal Ship: Acquisition Process Experience*, pp. 80–81.

59 Ibid., p. 80. Larry Lynn reportedly saw the initial $350 Navy funding and recognizing that it was inadequate, committed up to $170 million in DARPA funding.

60 David Evans, "The Navy's Blues," *New York Times*, June 8, 1996, p. 15. Figures for the missiles varied widely depending on the type being considered. The high-end cost was for a cruise missile on version. Other concepts suggested that missile costs could be drastically lower. (Discussion with Gen (ret.) Ray Franklin, former Dep. Commandant, US Marine Corps. March, 2003.)

61 Douglass interview.

development programs are often underestimated at the start. Moreover, this was an Other Transactions Authority development that assumed some level of cost share from industry and an opportunity for industry to practice new ways of achieving its goals that might be significantly less costly than the normal way of doing business. If the effort had had support, funding probably could have been increased later. The technology and acquisition process innovations associated with the Arsenal Ship are listed below:

Arsenal Ship Technology and Acquisition Innovations

- Acquisition Process
  - Utilized Section 845 Other Transaction Authority
  - Use broad descriptions of desired performance, rather than specific requirements
  - No formal systems specifications existed
  - Limited staffing in the Joint Program Office
  - Unit sail away price a firm requirement
  - Cost as Independent Variable approach
  - Exclusive use of off-the-shelf systems
  - Minimized government direction
- Command and Control
  - Off-board targeting, command, and control in a "remote missile magazine"
  - Flexible and robust data links
  - Joint connectivity architecture
- Materials and Structures
  - Signature reduction for ships
  - Passive survivability (e.g., compartmentalization, double-hull construction)
- Propulsion
  - Some form of electrical propulsion or auxiliary propulsion system
- Sensors
  - No long range surveillance or fire control sensors—these tasks to be performed remotely through robust data links
- Sustainment
  - Reduced manning
  - Automated engineering, damage, ship, and weapon control systems
- Weapons
  - Vertical Launch System (VLS) cells (approximately 500)
  - Integrated combat system with cooperative engagement capability

The fundamentally important change between Sea Shadow and Arsenal Ship was in the operational focus: from a Blue Water engagement of opposing fleets to support of littoral and land operations. Arsenal Ship was therefore important in providing a conceptual context for developing naval technology to support the new post-Cold War needs of the United States. The Lessons Learned Report stated:

> Technology is already available for breakthrough performance. Technologies still "under study" by the Government were readily incorporated in the Arsenal Ship designs based on COTS products. Areas of particular strength include: reduced manning; automation; information systems; communications/ connectivity; propulsion machinery; fire fighting; maintenance and logistics. Effective passive survivability and signature reduction technologies derived from previous Government programs are also available in the Marine and Aerospace industry. Combined, these resulted in improved performance with major savings for both acquisition and service life costs at little technical risk.[62]

Summary

Arsenal Ship might have played a more important role in the development of future naval technologies had Admiral Boorda continued as the CNO. However, as it was, it appears to have been a transitional vehicle employing some of the technologies that were first tested in the Sea Shadow (stealth, automation to reduce manning, robust data links, and some form of new propulsion system) and anticipating the technologies and operations that might ultimately be incorporated into the DD-21/X and other vessels. These ideas were transferred to the DD-21 Program and to the Naval Surface Combatant 21 (SC 21) Program and Captain (later Admiral) Hamilton was selected to move to the DD-21 Program from Arsenal Ship.

Although the formal Navy program was canceled, the basic concept of the Arsenal Ship as a means of providing mass littoral fire power is still being considered by some in the Navy, Marine Corps, and even the Army—where it is being pursued in the form of a missile launching barge towed to a combat arena by an Army seagoing tug. To overcome cost objections, one idea is to pursue the notion of Affordable Weapon System (AWS) missiles using commercial-off-the-shelf components to bring the cost of an individual missile down to $30,000.[63]

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62 Hamilton, *Arsenal Ship Lessons Learned*, Section 1.3.7.

63 Franklin interview.

DD-21 ZUMWALT-CLASS DESTROYER

Many of the technologies that are attributed as moving from the Arsenal Ship to the DD-21 were initially explored by Sea Shadow program. In fact, Admiral Hamilton, who was the Arsenal Ship PM, states that the Sea Shadow provided much of the technical basis for the Arsenal Ship and that the project was well informed by the previous effort.[64] These developments thus can be viewed as continuations of earlier efforts. While the short period of time in which the Arsenal Ship was an active program reduced the potential for this activity having a great impact, these concepts transferred over to the DD-21 effort and are thus a continuation of the impact of DARPA's naval technology effort.

DD-21 Development Chronology

The DD-21 was to be the first in the Navy's Surface Combatant 21 (SC 21) Program, a family of ships program designed to replace the fleet designed for sea control in the Cold War environment. According to the Navy, it was conceived as a multimission surface combatant that could accomplish both land attack and maritime dominance roles. It was to be armed with an array of land attack weapons such as those considered for the Arsenal Ship, to provide precise firepower at long ranges in support of forces ashore. The DD-21 could operate either independently or as an integral part of Joint and Combined Expeditionary Forces. To ensure effective operations in the littoral, the ship was to have "full-spectrum signature reduction, active and passive self-defense systems, along with cutting-edge survivability features, such as in-stride mine avoidance."[65] According to the Charter for the Program Executive Officer for DD-21:

> DD-21 will be designed using a Total Ship Systems Engineering (TSSE) process to integrate the entire ship, encompassing hull, mechanical, and electrical (HM&E) systems, as well as combat systems and Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) functions. The TSSE approach will result in warships that are more survivable, amenable to integration of future technologies, and adaptable to changing mission requirements than ever before. The DD-21 acquisition strategy calls for industry to offer competitive solutions to meet challenging operational and affordability requirements. The Navy expects to achieve significant life-cycle cost

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64 Hamilton interview.

65 Statement of the Honorable Lee Buchanan, Assistant Secretary of the Navy, RDA, to the US Senate Armed Services Committee, Sea Power Subcommittee, April 21, 1999.

savings from aggressive use of optimal crew strategies and technologies designed to maximize automation of traditional shipboard functions.[66]

Some of the key acquisition concepts incorporated into the new program are listed below.

- Early industry involvement to save on total life-cycle costs;
- Use of Section 845/804 contracting;
- Use of modeling and simulation technology as well as computer aided design;
- Use of commercial components;
- Integration of industry risk mitigation techniques;
- Revolutionary manning;
- Signature reduction; and
- Use of "Cost as an Independent Variable"[67]

The DD-21 was developed as a "Cost as An Independent Variable" program, with the goal of achieving O&S costs of $2,700 or less per hour in 1996 dollars. There was also a production Objective/Threshold cost of $650–$750 million from the fifth ship on. This pricing assumed the purchase of 32 DD-21s at a rate of 3 per year.[68]

The Navy desired a competitive development. However, getting a competition was initially difficult. Firms were reluctant to compete in a new Navy program so soon after the Arsenal Ship cancellation. After some initial difficulty, two teams competed to design the ship—one led by Bath Iron Works with Lockheed Martin Government Electronics Systems and the other led by Ingalls Shipbuilding with Raytheon Systems Co. and United Defense Limited Partnership. However, each team had representatives from the competing team observing the development process. It was planned that once a final selection was made, both shipyards would continue to compete as they each would assume responsibility for production of half of the total of 32 ships. This division of the procurement was intended to help maintain a viable military ship production capability in the United States.[69]

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66 US Navy, "Charter for the Program Executive Officer for DD-21: PEO DD-21," p. 2.

67 "DD-21 Zumwalt," Military Analysis Network, Federation of American Scientists, <http://www.fas.org/man/dod-101/sys/ship/dd-21.htm>.

68 Ibid.

69 Raymond Lisiewski and Edward Whitman, *DD-21: A New Direction in Warship Acquisition*, Arlington, VA: Program Executive Office, Surface Strike, 21 March 2000.

The ship's design (Figure II-2) reveals its lineage: the reduced signature and automation for reduced manning of the Sea Shadow and the weapons systems and data links of the Arsenal Ship.

Source: "DD-21 Zumwalt," *Military Analysis Network*, Federation Of American Scientists, <http://www.fas.org/man/dod-101/sys/ship/dd-21.htm>.

Figure II-2. DD-21 Schematic

DD-21 Technology and Acquisition Innovations

In testimony provided to the Seapower Subcommittee of the Senate Armed Services Committee in July 2001, Mr. John Young, Assistant Secretary of the Navy (Research, Development and Acquisition), characterized the DD-21 and its associated technologies as representing "the future of the surface Navy," and outlined the advanced technologies being developed in the DD-21 Program.[70] The DD-21, he stated, would "provide offensive, distributed, and precise firepower at long ranges in support of forces ashore." The ship's acquisition approach was constructed to achieve "maximum design

70 Statement of Mr. John J. Young, Jr., Assistant Secretary of the Navy (Research, Development and Acquisition) and Admiral William J. Fallon USN Vice Chief of Naval Operations Before the Seapower Subcommittee of the Senate Armed Services Committee on the FY 2002 Navy/Marine Corps Shipbuilding Programs July 24, 2001, p. 8.

innovation and flexibility, minimum cycle time from ship design to delivery, and significant cost savings using advanced commercial technologies and non-developmental items." The approach included "advanced design and construction techniques, and an innovative maintenance and support concept will result in reductions in procurement and lifecycle operating and support costs, including significant manning reductions along with improved quality of life for the crew."

DD-21 technologies cited included: "advanced weaponry to meet 21st century warfighting requirements" and the "automation needed to fight and survive with reduced manning, the essential key to reducing lifecycle costs for all Navy ships. Specific examples were the:[71]

- 155 mm Advanced Gun System (AGS), which has the range and lethality to meet USMC/JROC requirements for gunfire support for forces ashore.
- Integrated Power System (IPS)/Electric Drive: DD-21 will have all-electric architecture that provides electric power to the total ship (propulsion and ship service). Benefits include reduced operating costs, improved warfighting capability, and architectural flexibility.
- Optimized Manning through Automation: Initiatives, such as advanced system automation, robotics, human centered design methods, and changes in Navy personnel policies allow reduced crew size of 95–150 sailors while improving quality of life.
- New Radar Suite (Multi-Function Radar (MFR)/Volume Search Radar (VSR)): The radar suite provides DD-21, and other applicable surface combatants, with affordable, high performance radar for ship self-defense against envisioned threats in the littoral environment while reducing manning and life-cycle costs compared to multiple systems that perform these functions today.
- Survivability: Protection concepts that reduce vulnerability to conventional weapons and peacetime accidents under reduced manning conditions are key technologies required for the ship design.
- Stealth: Acoustic, magnetic, infrared and radar cross section signatures are markedly reduced compared to the DDG 51 Class and make the ship less susceptible to mine and cruise missile attack in the littoral environment.

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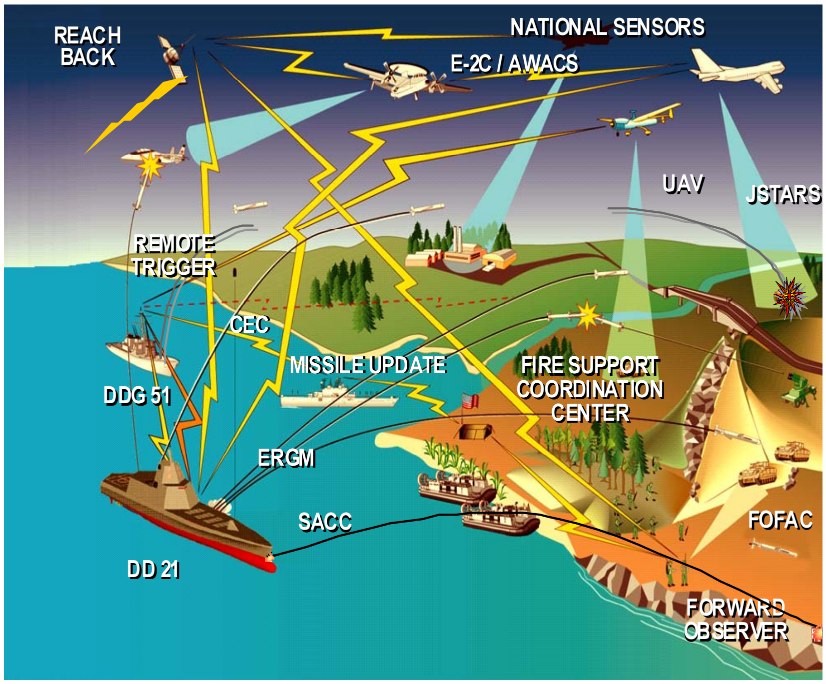
71 Ibid., pp. 8–9.

Both the technologies and the acquisition approach derive substantially from the earlier Arsenal Ship effort.[72]

Figure II-3 illustrates the mission tasking that was to have been assigned to DD-21s. Like the Arsenal Ship, the DD-21 was planned to have a standoff support capability responding to requests for fire from troops ashore.



Source: DD-21 Program website, now inactive.

Figure II-3. DD-21 Operations

However, in November 2001, the Navy announced that it would issue a revised Request for Proposal (RFP) for the Future Surface Combatant Program. The DD-21 program would be changed and called the DD X "to more accurately reflect the program purpose, which is to produce a family of advanced technology surface combatants, not a single ship class."[73] According to the news release, the DD X program would—

> …provide a baseline for spiral development of the DD(X) and the future cruiser or "CG (X)" with emphasis on common hullform and technology development. The Navy will use the advanced technology and networking capabilities from DD(X) and CG (X) in the development of the Littoral Combat Ship with the objective being a survivable, capable near-land

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72 Hamilton interview.

73 DoD News Release Number 559-01, November 1, 2001.

> platform to deal with threats of the 21st century. The intent is to innovatively combine the transformational technologies developed in the DD(X) program with the many ongoing R&D efforts involving mission focused surface ships to produce a state-of-the art surface combatant to defeat adversary attempts to deny access for US forces.[74]

The announcement said that the Navy would continue to review the program and narrow the competition until selection of a single contractor in the spring of 2002. On April 29, 2002, the Navy announced that Northrop Grumman Ship Systems was selected as the lead design agent for the DD(X) Program.

Summary DD-21/DD(X)

DD(X) continues three decades of naval research and development concerned with stealth and standoff precision strike. DARPA has played an instigating role to develop and demonstrate disruptive concepts, but the impetus for change has not been strong, and high-level support has been episodic. Consistent support and internal constituency would be necessary to counter the objections of existing ship programs that stand to be disrupted, as well as to keep disruptive programs focused on a narrow set of high-priority missions. Without that support and focus, there has been continual experimentation with operational and technical concepts rather than progression to production and deployment. However, as suggested by the design objectives for the DD-21, the Navy does appear to accept the need to design its future surface combatant fleet around many of the basic concepts that DARPA helped conceive and demonstrate.

SUMMARY OF DARPA SUPPORT

The analysis of the naval surface warfare embodied in the Sea Shadow, Arsenal Ship, and DD-21(X) suggests the following conclusions:

- A host of potentially useful technologies are being investigated or might warrant investigation. There is a consensus, however, about several technologies that will help the Navy to be effective in the new littoral battlespace. Among these are:
  - o Materials, structures, and design for stealthy operation
  - o Automation that aids in ship command and control as well as reducing manning requirements
  - o Technologies to assist in combat decision-making and targeting
  - o Sufficient firepower to sustain ground and sea support early in a conflict

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74 Ibid.

- Many of the innovations in contracting and the use of commercial components that were utilized in the course of these ship development programs showed promise as a new way the Department of Defense can gain access to commercial technologies and leverage commercial R&D funds to achieve military technology goals at greatly reduced costs. These efforts were not, however, without cost. For example, contractors suffered immediate losses with the cancellation of the Arsenal Ship program. This had an impact on the contractual structure of the subsequent DD-21 program. Moreover, these new approaches still do not apply to the all important production phase.
- Incorporating stealth technologies into Naval platforms works and is an important innovation for fighting against a sophisticated enemy.
- Reduced manning is another important goal, but it will require persistent effort and significant R&D before it will be implemented widely. The Navy expressed concerns in regard to reduced manning through the different development efforts, including: performance of daily tasks, firefighting, and ship protection. While the 95-person crew forecast for the DD(X) is far greater than the 50-person goal of the Arsenal Ship, even achieving such a number will be a challenge.
- One of the most difficult tasks in innovation is overcoming the existing mindset to gain acceptance of the new technology. This is not unique to the programs under study here or to the Navy itself. However, the Navy's approach of building the first ship in a class, rather than engaging in prototype development, increases challenges to innovation in Naval vessels.
- Innovative DARPA acquisition procedures stimulated participation in development programs and helped further the development goals of each new ship program.

ATTACHMENT A

MEMORANDUM OF AGREEMENT (MOA) FOR JOINT NAVY/DARPA ARSENAL SHIP DEMONSTRATION PROGRAM

Source: US Government, Arsenal Ship Lessons Learned Report, http://www.fas.org/man/dod-101/sys/ship/docs/arsenal/sec1.html.

Purpose

The purpose of this document is to establish a joint Navy/DARPA agreement as to the objectives, roles and responsibilities, schedule, and funding for the Arsenal Ship demonstration program.

Background

Arsenal Ship is a high priority program for the Navy to acquire a new capability for delivery of large quantities of ordnance in support of land and littoral engagements. Key to both Arsenal Ship's affordability and operational flexibility is off-board integration of all but the most rudimentary C4I. The ships are conceived to be theater assets that will operate under the authority of the joint Commanders-In-Chief (CINCs) and will receive their targeting along with command and decision information from other assets. Early in Arsenal Ship's life this control will be exercised through an Aegis platform, though as other assets mature, control will transition to aircraft such as AWACS or an E-2 with CEC-like capability and eventually to the Marine or Army shooter on the ground. Thus, the Arsenal Ship will not be fitted with long range surveillance or fire control sensors, but will be remotely controlled via robust data links. The data links will be secure, redundant and anti-jam in order to provide high reliability in the connectivity of the Arsenal Ships in high jamming operational scenarios. The program overall is an attempt to leverage the significant current joint investment in Link 16 and CDC. The Arsenal Ship's survivability will be primarily achieved through passive design techniques. While active systems are not ruled out, they must be consistent with overall cost and manning goals. These design goals will allow the Arsenal Ship to have a very small crew (potentially, none at all), which will be a key ingredient in minimizing its life cycle costs. It is expected that the Arsenal Ship will transit and operate independently but when in a hostile environment, its defense will be enhanced by working cooperatively with other elements of the force. It is envisioned that the Arsenal Ship will be a large hull designed so that the weapons carried onboard are protected from damage and the ship is "virtually unsinkable" if hit by missiles, torpedoes, or mines.

This demonstration program is a non-ACAT program that has been created to evaluate this new capability while minimizing the risks in acquisition of approximately 6 ships (to include conversion of the Arsenal Ship Demonstrator to a fleet operational unit at low cost). To ensure that the program remains affordable, a firm cost threshold for the production ships has been established. This program will be conducted using DARPA's Section 845 Agreements Authority so as to allow industry wide latitude in satisfying the Navy's requirements within this threshold. Agreements will be structured to allow trade-offs between cost and performance. Program success will be judged by the extent to which the Arsenal Ship meets operational requirements.

A second purpose for this demonstration program is to accelerate the Navy's ongoing acquisition reform activities focused on buying improved ships at a lower cost. To this end, the joint program will focus on exploiting DARPA's culture and experience in prototyping system programs. We anticipate the production Arsenal Ship contracts will serve as a model for future streamlining.

Technical Objectives

The Arsenal Ship is intended to provide a large quantity of (approximately 500) vertical launch systems (VLS) with the capability to launch a variety of weapons for strike, fire support, and area air defense. The exact number of VLS missiles will be determined during the program by optimizing the survivability, performance, sustainability and costs. The demonstration program will highlight Arsenal Ship's capability as a force multiplier to the Marine Corps, Army, and full array of joint forces. In that regard, it is recognized that certain weapons do not yet exist in the inventory that would allow the full capability to be demonstrated for all missions. No new weapons developments or significant enhancements to weapons are to be pursued as part of this program. Instead, demonstrations should be planned and structured such that significant communications, architecture, and data link functions are evaluated. The goal of the program will be to achieve a balanced design that satisfies the thresholds consistent with the ship's concept of operations (CONOPS).

The demonstration program must show that the production Arsenal Ships are suitable for performing their mission within prescribed cost constraints. To this end, its objectives are to demonstrate:

1. The performance of the mission for 90 days.
2. The architecture, communications, and data link functions to satisfy the Arsenal Ship CONOPS.
3. The capability for remote launch of strike, area air warfare and fire support weapons. It is envisioned that the test program will include:
   a) Salvo launch of up to 3 Tomahawk missiles in 3 minutes.
   b) Single SM2 launch using the arsenal ship as a remote magazine for a Cooperative Engagement Capability (CEC) ship
   c) Single Tomahawk launch using the arsenal ship as a remote magazine for air directed and shore based targeting
   d) Single ATACMS launch from a VLS cell in support of a naval surface fire control mission digital call for fire
4. That the proper balance between passive survivability and active self defense will be sufficient for the expected operating scenarios.

Cost Threshold: Industry Goal—$450M/Program Threshold—$550M

The acquisition cost threshold is based on the average Navy SCN end costs for the five follow ships acquired after this demonstration pro-gram, expressed in FY 1998 dollars. The costs of the weapons are not included.

Life Cycle Costs

Industry will be tasked to perform the life cycle cost analyses to demonstrate the operating and support costs for their Arsenal Ship design over a 20 year life. This will ensure that the tenets of the program including reduced manning and innovative operating concepts remain focused on minimizing life cycle costs.

Schedule

The goal of the demonstration program is to have the ship in the water and ready to start meaningful testing in the year 2000. The program manager will maintain a detailed schedule toward this end and present the plan for approval by the Steering Committee. The basic acquisition strategy for this program is to maximize industry involvement through a competitive multi-phase approach to encourage the maximum innovation within the limits of the cost thresholds. The Government, through the program office, will coordinate with industry to ensure the availability of information that the industry teams need to make informed trades.

Funding

The cost of the R&D program for this demonstration Arsenal Ship will not exceed $520 million including the cost of concept development and competition. These funds will be provided jointly by the Navy and DARPA as follows:

Dollars in Millions

	FY 1996	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001
Navy	$4.0	$25.0	$141.0	$90.0	$80.0	$10.0
DARPA	$1.0	$15.0	$47.0	$50.0	$36.0	$21.0

The Navy will provide its share of the funds to DARPA at the beginning of each fiscal year.

Roles and Responsibilities

This joint Navy/DARPA demonstration program will be conducted under the auspices of DARPA's Section 845 Agreements Authority. DARPA will lead the demonstration program and will transition the leadership to the Navy in the later stages of the program, upon mutual agreement of the parties.

The program will be managed by a joint Navy/DARPA program office with the Program Manager reporting to DARPA. A small program office is envisioned. DARPA, Naval Sea Systems Command (NAVSEA), and the Office of Naval Research (ONR) will initially each provide two billets. It is expected that the program office will grow to a maximum of three billets each as the program grows to maturity.

The Navy shall develop a concept of operations (CONOPS) for the program that will be reviewed and considered for update as the program develops. The program office will use the CONOPS to guide the trade studies to be conducted by industry.

The Program Manager will develop a program plan including major decision milestones, and the development of a program transition plan. The Steering Committee will approve the initial program plan and thereafter will conduct quarterly reviews to assess progress and provide guidance to the Program Manager.

The Steering Committee will be as follows

- Director, TTO—DARPA Chairman
- Deputy Assistant Secretary of the Navy (DASN, Ships)
- Assistant Director, TTO for Maritime Programs—DARPA
- Director, Surface Warfare Plans/Programs/Requirements
- Branch—OPNAV (N863)
- PEO for Surface Combatants
- Office of Naval Research (ONR33)

An Executive Committee consisting of:

- Assistant Secretary of the Navy (RD&A)
- Director of Surface Warfare (N86)
- Director, DARPA
- Commander, NAVSEA
- Chief of Naval Research

will review the program at major decision milestones to evaluate the validity of program cost thresholds and provide re-direction as necessary.

Term of Agreement

It is expected that this MOA shall remain in effect for the duration of the demonstration program. Early termination of the program due to funding unavailability, lack of legal authority or other reason beyond the control of the parties shall be a basis for termination of this MOA. Any termination shall be preceded by consultation among the parties.

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III. THE DEVELOPMENT AND DEPLOYMENT OF PRECISION GUIDED MUNITIONS (PGMS) FOR STANDOFF ATTACK

Richard H. Van Atta and Ivars Gutmanis

This chapter reviews the major factors that have influenced the development and deployment of Precision Guided Munitions (PGMs) for use in conventional standoff attack. It provides background on the technologies and concepts underlying PGMs. Chapters IV and V discuss disruptive capabilities enabled by PGMs in concert with other systems.

The US DoD Handbook of Military Terms defines PGMs as weapons that use "a seeker to detect electromagnetic energy reflected from a target…and, through processing, provides guidance commands to a control system that guides the weapon to the target." US Army terminology defines PGMs as "a munition capable of locating, identifying, and maneuvering to engage a point target with an accuracy sufficient to yield a high probability of destruction."[1] PGMs can be distinguished between those that are delivered by a powered system (a missile or rocket) versus unpowered (usually a simple bomb). For the purposes of analysis, the following distinction is most important:

> *Command-guided weapons* are munitions (usually small rockets or bombs) that are guided to a fixed location by commands given after launch. Commands may be given based on illumination reflected off the target by an energy source (usually a laser) or by an internal navigation unit (e.g., GPS or terrain mapping). In the former case, these weapons usually require the individual designating the target to do so until it is hit.
>
> *Autonomous homing weapons* use seekers or sensors to home in on a fixed or moving target without having to be designated externally. These are sometimes referred to as "fire and forget" weapons.

As weapons have become more complex with the increasing miniaturization and integration of electronics, there are emerging weapons that employ multiple types of guidance. For instance, the GBU-15 TV-guided glide bomb was implemented by simply putting tailfins and a TV seeker nose on a standard bomb. The AGM-130 turned the GBU-15 into a "stand-off" missile by adding a rocket booster, and the AGM-130TJ replaced the rocket booster with a small jet engine, turning the weapon into a cruise missile (Goebel, 2001). The Joint Air to Surface

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1 TRADOC Pamphlet 525-5 Force XXI Operations, August 1, 1994.

Standoff Missile (JASSM) is a cruise missile that combines GPS/INS guidance with an infrared seeker; thus, it can be considered, at least partially, to be an autonomously homing PGM.

PGMs also may be distinguished by the type of application: a) air-to-ground; b) ground-to-ground; c) air-to-air; and d) ground-to-air ("ground" also includes surface ships). PGMs that are targeted against ground or surface targets can be further categorized as those designed and deployed against fixed targets and those for mobile targets.

This chapter will not focus on air-to-air or ground-to-air systems because they are generally short range and used for either defensive or close-in, one-on-one engagement, rather than standoff attack. It will also not focus on command designated systems that do not use internal navigation.

FACTORS AFFECTING DEVELOPMENT

Several factors have influenced the research and development, manufacture, and deployment of PGMs by DoD:

1) **The development and deployment of strategic and tactical weapons by potential enemies.** The most significant driver of the US focus on and investment in PGMs occurred in the late 1960s and early 1970s with the buildup by the USSR of advanced tactical capabilities in Eastern Europe. More recently, the emergence of several "rogue states," such as North Korea or Iraq, with a potential to attack the United States or areas of interest to the US, represents another example of the impact of an identified threat on the advancement of US munitions.

2) **Experience in foreign military actions by the US and its allies.** North Korea's invasion of South Korea across the 38th parallel on June 25, 1950 motivated increasing emphasis and funding by the US for improved munitions and delivery systems. The 1973 Arab-Israeli War demonstrated the importance and benefits of advanced munitions and raised debate as to their value in future conflicts.[2] Military operations during Desert Storm and in Kosovo underscored the value of precisions munitions.[3] But perhaps the most significant drivers of the development of PGMs by the US military were the demonstrated difficulties and frustration with hitting targets during the Vietnam War. On May 10, 1972, two Air Force pilots using their laser-designated BOLT guided bombs scored a direct hit on the Paul Doumer Bridge in South Vietnam, resulting in its destruction. Prior to this, the bridge had been bombed

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2 James Jay Carafano, "Myth of the Silver Bullet: Contrasting Army-Air Force Perspectives 'Smart Weapons' After the 1973 Arab Israeli War and the 1991 Gulf War," *National Security Studies Quarterly*, Winter 1998, pp. 1–20.

3 Nick Cook, "War of Extremes: Never Before Has Air Power Played Such a Central Role in the Conduct and Outcome of an Entire Conflict," *Jane's Defense Weekly*, July 7, 1999. See also Benjamin S. Lambeth, "Storm Over the Desert," *Joint Force Quarterly*. Winter 2000–2001, pp. 30–34.

almost continuously for 3 years at the cost of 1,250 tons of munitions. The use of the BOLT system in one sortie of two aircraft had accomplished what the previous 1,500 gravity bombs and 200 sorties could not.[4]

3) **Technological advancement in science and technology.** Advancements in component technologies (airframe, propulsion, navigation, guidance) have accelerated the performance of PGMs. The rapid advance of microelectronics technology and in sensors technology—laser, infrared (IR), optical, and others—and advances in rockets, missiles, and the submunitions have allowed PGMs to be targeted with increasing precision onto more difficult targets.[5]

4) **General DoD funding levels.** The size of the DoD budget has varied with the defense requirements and actual or possible military engagements with enemy forces. These fluctuations have affected the advancement and deployment of precision munitions. In the early 1980s DoD was forced to defer the start of the Multipurpose Lightweight Missile System (MLMS) and to postpone advancement of the MLMS "fire and forget" seeker as the result of limited funding. A number of other programs for advanced PGMs and their delivery systems were canceled or postponed.

5) **Allocation of the DoD budget.** During the Vietnam War, much of the R&D-related programs and funding for advanced munitions were reduced as the DoD funding was routed to the Vietnam combat operations.[6] Competition among the Services also impacted the development and deployment of specific advanced munitions systems.

LEGACY OF WORLD WAR II

The demands of warfighting in World War II (WWII) resulted in significant improvements in bombs, rockets, and early missiles. Germany, the US, and the UK developed an array of guided bombs, mostly command guided, but in some cases terminally guided using TV, radar, and infrared technologies.[7] The US GB series of winged glide bombs was augmented with a variety of guidance systems, including infrared and active radar seekers and TV imagers. The

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4 Redstone Arsenal, "Redstone Arsenal Complex Chronology: The Redstone Arsenal Era, 1950–1989," The Redstone Arsenal, Huntsville, Alabama, 2001, <http://www.redstone.army.mil/history>. See also General Accounting Office (GAO), *Defense Acquisitions Reduced Operational Effectiveness of Joint Standoff Weapons: Report to the Chairman, Subcommittee on Defense, Committee on Appropriations*, House of Representatives, Washington, DC, 1999.

5 Defense Science Board "Precision Weapons" in *Defense Science Board 1996 Summer Study Task Force on Tactics and Technology for 21st Century Military Superiority*, Washington, DC, October 1996. See also Justin P. White, "Maverick Missile Upgrade: A Case for a Legacy System," *Armed Forces Journal International*, 135:20 June 1998, pp. 11–15, and Michael A. Dornheim, "Lofty Goals Spur Technical Advances," *Aviation Week*, October 12, 1998, pp. 48–49.

6 John J. Holst, and Uew Nerlich, *Beyond Nuclear Deterrence: New Aims, New Arms*, New York: Crane, Russak & Company, 1977.

7 H. A. Ory, M. B. Schaffer, B. F. Jaeger, and J. J. Kichel, *Precision-Guided Munitions for Surface Targets*, Santa Monica, CA: R&D Associates, March 1975.

VB series munitions (conceptually similar to the German Fritz-X weapon) were finned bombs, which proved more successful than the GB munitions. These were modified standard aerial bombs fitted with a new tail featuring a gyro stabilization system, a pair of rudders, and a tracking flare. A radio control system allowed a bombardier to direct the bomb with a joystick, with launch aircraft remaining on course while the operator guided the bomb into the target.[8]

The Navy's Bat (ASM-N-2) anti-shipping weapon was one of the more capable guided weapons developed during World War II. The original concept was for a television-guided anti-ship weapon, with the TV guidance system developed by RCA. However, television in the 1940s was premature for use in combat. So instead Bat used fully active radar homing. After being dropped, the bomb glided toward the target on a preset course using a gyrostabilizer system. As it neared the target, the bomb locked onto it with its radar. The Bat was put into operation in May 1945. It was effective against Japanese shipping and, with modified guidance systems, was also used against ground targets.[9]

PGM DEVELOPMENTS IN THE 1950s

Guided Bombs

The 1950s was a period of dormancy in the development of tactical precision weapons.[10] Interest in these weapons declined in the years immediately after World War II. The electronics technology, based on vacuum tubes, was insufficiently reliable for combat use, and the experimental seeker systems suffered from low sensitivity and contrast. Research continued at a low level, with some increased experimentation during the Korean War, using the World War II-developed RAZON guided bomb against North Korea bridges. After the Korean War, focus shifted to nuclear weaponry, and there were few resources allocated to tactical guided munitions. The increasing intensity of the Cold War and the launching of the Soviet Union's SPUTNIK in 1957 increased the US R&D focus on strategic weaponry, rather than on tactical munitions.

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8 R. J. Heaton, and C. W. Smoots, *Introduction to Precision Guided Munitions*, Chicago, IL: Guidance and Control Information Analysis Center, May 1983.

9 Lulejian & Associates, *ARPA/DNA Long Range Research & Planning Program*, Panel Minutes, Falls Church, VA: Lulejian & Associates, 1974. Also Holst and Nerlich.

10 Adding to the problem, the Army Ordnance Department—not the Air Force—was responsible for all high-explosive fragmentation and semi-armor piercing bombs. The Army gave little priority to advancing guided bombs as it sought to position itself in the development of ground-based missiles.

Missile Systems

While the Air Force was assigned the role of developing and deploying strategic intercontinental ballistic missiles, the Army retained a major role in the development of air defense missiles in the 1950s, in particular various NIKE systems. In just 6 years, the NIKE project progressed from drawing boards to the intercept of dozens of remotely piloted B-17 bombers over the desert of Southern New Mexico.[11] The NIKE-AJAX, initially called NIKE-B and later NIKE-HERCULES, was designed for continental United States and field operation in three difference modes: surface-to-air, low-altitude, and surface-to-surface. HERCULES contained no vacuum tubes, only solid-state components (except for the beacon transmitter), and it used solid propellant rather than liquid fuel. These changes enhanced the reliability and logistics of the system.

When the Air Force was created in 1947, it was given responsibility for pilotless aircraft, strategic missiles, and area air defense, while the Army had responsibility for point air defense.[12] Hence, both Services saw missiles as an extension of their own areas of expertise—artillery for the Army and the airplanes for the Air Force. The Air Force focused on long-range surface-to-surface missiles—partially to differentiate from the Army's artillery focus.[13] One of the most prominent of the Air Force developments was the SNARK, a jet-engined, winged "flying bomb." This early cruise missile was plagued with problems and its intended customer, the Strategic Air Command, became disenchanted. While the SNARK was activated for a short period, it was quickly phased out in favor of ballistic missiles.[14] With the first launches of Thor and Atlas ICBMs in 1959, cruise missiles were abandoned for strategic missions.[15]

Another Air Force missile, the MATADOR, was designed for shorter ranges—175 to 500 miles. Developed in the early 1950s, the MATADOR was initially line-of-sight guided, but because of range limitations and problems with jamming, the guidance was changed to a new technology developed by Goodyear aircraft—the Automatic Terrain Recognition and Navigation (ATRAN), which was the precursor to terrain contour matching Terrain Comparison

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[11] Redstone Arsenal, *Redstone Chronology*.

[12] Ory et al., *Precision-Guided Munitions for Surface Targets*.

[13] BDM Corporation, *History of Strategic Air and Ballistic Missile Defense 1945–1955*, Washington, DC: BDM Corporation, 1956.

[14] Similar problems plagued the Air Force's Navaho, a turbo-jet powered missile developed by North American (Werrell, 1985, pp. 97–103).

[15] John Birkler et al., *A Framework for Precision Conventional Strike in Post-Cold War Military Strategy,* Santa Monica, CA: RAND, 1996.

(TERCOM). The MATADOR was fielded until 1965, when it was replaced by the PERSHING missile in Europe.[16]

During the Korean War, the US Navy became frustrated with unguided weapons for ground attack, and in 1953 it began development of a tactical air-to-ground guided missile, the ASM-N-7 Bullpup, which was first fielded by the Navy in 1959.[17] It was a relatively small missile with a 250-lb warhead, which was optically tracked and manually guided by the pilot using a small control stick to transmit radio commands. An improved variant, the ASM-N-7A, which was redesignated AGM-12B in 1962, was known as "Bullpup-A." The AGM-12B was not much different from the guided weapons used by the Germans during WW II.

PGM DEVELOPMENTS IN THE 1960s

In the 1960s, PGM development was accelerated by several factors. The Cuban missile crisis in 1962 pointed to the vulnerability of the US to missile attacks. It also highlighted lack of "surgical strike" capabilities. The US experience in Vietnam also demonstrated the ineffectiveness of US precision strike capabilities. The Vietnam experience impacted US assessments of its ability to counter the threat from the Soviet Union and the Warsaw Pact in Europe.[18]

The development of smart munitions in the 1960s drew upon the science and technology advances in several fields:[19]

1. Microelectronics
   - 1.1 Reduction of the minimum feature size of transistors
   - 1.2 Reduction of interconnects size
2. Computing and data processing
   - 2.1 Developments in digital computers
   - 2.2 Commencement of artificial intelligence
   - 2.3 Commencement of interactive graphics
   - 2.4 Advances in computer image interpretation
   - 2.5 Rapid digital data processing

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16 Holst and Nerlich, *Beyond Nuclear Deterrence*.

17 George B. Berke, ed., *Smart and Precision Munitions,* DMS Market Studies, Alexandria, VA: *Jane's Information Group*, 1989.

18 Dr. N. F. Wikner, "A Balance of Theater Nuclear Forces: Can We Count? Where are the Reloads?" *Armed Forces Journal International*, May 1983, pp. 92–101.

19 Charles T. Fox, *Precision Guided Munitions: Past, Present, and Future*. Maxwell AFB, AL: Air War College, April 14, 1995; and Robert A. Pape, "Limits of Precision-Guided Air Power," *Security Studies*, 7:93-114, Winter 1997–1998, pp. 71–79.

3. Lasers
    3.1 Commencement of high energy lasers development
    3.2 Application of laser design
4. Materials
    4.1 Commencement of polymer composites
    4.2 Commencement in use of matrix resins
    4.3 Increases in strength (weight factor of composites)
    4.4 Commencement of new material use in composites
5. Propulsion Systems
    5.1 Advances in low-weight high thrust system design
    5.2 Advances in dynamic fuel control

In particular, the semiconductor industry advanced rapidly in the 1960s with the advent of solid-state transistors and the invention of the integrated circuit, which significantly reduced the dimensions and improved the reliability of electronics in munitions. A breakthrough in quantum mechanics stimulated the development of a new source of illumination, the laser, which first appeared in the early 1960s, and the introduction of the first practical advanced portable illumination system. The Defense Advanced Research Projects Agency (DARPA) facilitated advancement in laser technology with a comprehensive research program that began in 1962.

Guided Bombs

Although work on guided glide bombs faded in the 1950s, technological advances and the war in Vietnam resurrected them. Confronted with difficult targets and strong air defenses in the bombing campaign against North Vietnam, the US Navy and Air Force developed improved glide bombs guided by television and laser beams, and such weapons have been refined ever since. Technological advances were key to the development and operational use of television-guided and laser-guided bombs. The performance of glide weapons in the 1940s and 1950s suffered from the available crude electronics technology. Infrared sensors and radar were in their infancy and had minimum performance and reliability. By the 1960s, solid-state electronics made electronics systems much more compact and reliable; thus, guided conventional weapons became much more practical. The development of guided bombs proceeded on two technology paths—those guided by television and related imaging sensors and those that locked onto laser light reflected from a target.[20]

Both the Navy and Air Force developed bombs guided by television, or "electro-optic" (EO) sensors. The Navy's EO-guided bomb development, the AGM-62 WALLEYE, began in

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20 Birkler et al., *A Framework for Precision Conventional Strike*.

1963, with production beginning in early 1966.[21] The image provided by the WALLEYE's EO seeker was displayed on a TV screen in the controlling aircraft, and the operator locked the seeker onto the target using crosshairs in the display. The WALLEYE remains in the Navy inventory and was employed in the Gulf War. The Air Force EO glide bomb, GBU-8 HOBOS (Glide Bomb Unit 8, Homing Bomb System), began in 1967 with its first combat use in Southeast Asia in 1969. HOBOS consists of a guidance control unit (GCU) fitted to either a Mark 84 2,000 pound or Mark 118 3,000-pound bomb. Both the WALLEYE and the HOBOS ostensibly had "fire and forget" capability, in which the operator could lock it onto a target, though in practice this proved unreliable, particularly under low lighting conditions and changing contrast.

The idea of using a laser to designate targets traces back to 1960 when, at the US Army Missile Command in Huntsville, Alabama, the idea of laser-guided artillery shells was considered, and studies were conducted on laser designator and seeker systems. In the early 1960s, Martin Marietta performed experiments with laser targeting systems, and in 1964 it demonstrated such a device to the USAF. A year later Texas Instruments discussed the idea of a "laser-guided bomb" (LGB) and the Air Force provided initial funds for the development of an LGB. Early tests were conducted with M-117 bombs with moveable tailfins, resulting in the BOLT-117 (Bomb Laser Terminal-117), the first LGB, tested in April 1965. The BOLT-117 consisted of a standard 750-pound bomb case with a KMU-342 laser guidance and control kit. While initial results were poor, design modifications resulted in a much improved weapon. TI was subsequently awarded a contract for 50 PAVEWAY guidance kits (PAVE for Precision Avionic Vectoring Equipment), and prototype LGBs were sent to Vietnam in 1968 for operational testing on different glide bombs.[22]

The BOLT-117, while limited in production and use, had a revolutionary impact on airpower. Laser guidance kits turned standard "dumb" ordnance into "smart bombs", yielding a 100-fold increase in effectiveness compared with free-fall, unguided bombs. The PAVEWAY LGB kits, costing only a few thousand dollars, were produced in great quantity. Thousands of them were used in Vietnam to destroy bridges that had survived many conventional bombing raids. While the earliest laser-designated bombs were limited to use in daylight, as their target acquisition system used an electro-optic seeker, a new generation of infrared seekers overcame this deficiency.[23]

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21 Greg Goebel, "Dumb Bombs & Smart Munitions," *Vectorsite*, 2001, <http://www.vectorsite.net/ twbomb.html>.

22 Ibid.

23 Fox, 1995; Goebel, 2001; Carafano, 1973.

Missiles

A larger version of the BULLPUP, the AGM-12C, was introduced into service in 1963. The USAF also ordered a variant of the BULLPUP-B, later designated AGM-12D. Both the BULLPUP-A and BULLPUP-B were employed in the Vietnam War. A major problem with the Bullpup was its guidance system, which required the pilot to guide it visually using a joystick, left the launch aircraft exposed until weapon impact. In addition, the Bullpup's warhead was too small to seriously damage heavy targets like bridges.

To address these deficiencies the Air Force in 1965 sponsored the development of a relatively small missile that was intended to destroy armor, bunkers, and other battlefield targets. In 1968, a development contract for such a missile, the MAVERICK, was awarded to Hughes. The MAVERICK is a TV-guided missile that is locked onto its target by the operator with crosshairs on the aircraft display and then proceeds to the target without further operator intervention. An initial production contract was awarded in July 1971, and the AGM-65A MAVERICK entered service with the USAF at the end of 1972.[24]

Improvements in air defense systems through the 1950s led to the development of a missile that homed in on radar emissions to destroy the radar. While the British and French worked on such a missile, the US Navy developed an anti-radar missile, or "ARM." The Navy began developing this weapon in 1961, basing it on the SPARROW air-to-air missile, and in 1963 it went into production as the AGM-45A SHRIKE. The SHRIKE is a solid-fuel rocket-powered missile fitted with a blast-fragmentation warhead with a proximity fuze. The operator sights the SHRIKE on an emitter, and launches it after it reports a lock. It rides down the beam to the emitter and destroys it.[25]

PGM DEVELOPMENTS IN THE 1970s

In the early 1970s, the cost of US military operations in Vietnam, mounting taxes, and an inflated economy all took their toll on technology-related military budgets. At the same time, arms talks with the Soviet Union were continuing with general expectation of agreement. The treaty limiting ABM systems signed by President Nixon and Secretary General Brezhnev on May 26, 1972, affected many US programs for the development of rockets and missiles. At the same time, especially with studies co-funded by the Defense Nuclear Agency (DNA) and DARPA, there emerged considerable attention in the defense policy and technology community

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24 Ibid.

25 Ory, *Precision-Guided Munitions for Surface Targets*.

on the broader implications of precision-guided munitions for national security policy. This interest was stimulated by a combination of [1] a refocusing of attention on the Soviet conventional presence in Eastern Europe, and [2] an appreciation of new technological possibilities driven largely by microelectronics. The experiences of both sides in the 1973 Arab-Israeli War added to the urgency to improve precision strike capabilities. Stimulated by the galvanizing impact of the Soviet threat, the support and funding for US defense increased after 1975, with significant increases in the defense-related R&D activities aimed at advancing the performance of PGMs.[26]

The following principal fields of science and technology contributed to the advancement of PGMs in the 1970s:[27,28,29,30]

1. Microelectronics
    1.1 Commencement of VLSI systems design
    1.2 Commencement of IR imagery systems
    1.3 Improvements in lower voltage requirements
    1.4 Improvements in interconnect technologies
    1.5 Further advances in minimum feature size of transistors
    1.6 Rapidly increasing number of transistors per chip
2. Computing and data processing
    2.1 Advances in digital computer
    2.2 Advances in time sharing systems
    2.3 Advances in artificial intelligence
    2.4 Interactive computing development
    2.5 Rapid reduction in the size of computing systems
    2.6 Advances in density of computing systems
3. Lasers
    3.1 Advances in laser beam riding or homing systems
    3.2 Advances in Laser Target Market (LTM) technologies
    3.3 Advances in Extremely Sensitive Low Level Laser Systems (LLLSS)

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26 William Mathews, "Debate on Wartime Accuracy is Renewed," *Air Force Times*, 57, July 21, 1997, pp. 29–34.

27 Fox, Charles T., *Precision Guided Munitions: Past, Present, and Future*. Maxwell AFB, AL: Air War College, April 14, 1995.

28 Pape, Robert A., "Limits of Precision-Guided Air Power," *Security Studies*, 7:93-114, Winter 1997–1998, pp. 71–79.

29 Redstone Arsenal, "Redstone Arsenal Complex Chronology: The Redstone Arsenal Era, 1950–1989," The Redstone Arsenal, Huntsville, Alabama, 2001, <http://www.redstone.army.mil/history>.

30 SIA (Semiconductor Industry Association), *The National Technology Roadmap for Semiconductors*, San Jose, CA 2000.

4. Materials
    4.1 Advances in ceramic matrix composites (CMC's)
    4.2 Commencement of super alloy technologies
    4.3 Commencement of carbon fiber and matrix resins applications
    4.4 Development of materials with stealth properties
5. Radars and sensors
    5.1 Advances in Synthetic Aperture Radar (SAR)
    5.2 Development of Moving Target Sensors (MTI)
    5.3 Commencement of millimeter wave (MMW) radar development
    5.4 Advances in two dimensional phased array development
    5.5 Continuations of advances in I-R technologies

Many of these were the outcomes of research funded by DARPA and the Services in the previous decade. Many of these advances were integrated into DARPA's ambitious Assault Breaker program, which demonstrated a systems-of-systems approach to standoff precision strike. (See Chapter IV in this volume.)

Guided Bombs

In the early 1970s, the initial PAVEWAY was replaced by the PAVEWAY II, which featured an enhanced but also simpler and cheaper seeker head and pop-out fins to improve the weapon's glide characteristics and make it easier to fit to an aircraft. The new LGBs based on the PAVEWAY II were given the designations GBU-12 (225 kilograms), GBU-16 (450 kilograms), and GBU-10 (900 kilograms). The PAVEWAY II required the launch aircraft to operate from medium altitude, leaving the aircraft vulnerable to ground defenses; thus in 1976 the USAF issued a requirement for another generation of PAVEWAY weapons, the PAVEWAY III.

Missiles

The AGM-88 High Speed Anti-Radar Missile (HARM) was developed to provide an anti-radiation weapon that was faster and longer in range than the SHRIKE. The US Navy began studies that led to HARM in 1969, a development contract for the weapon was awarded to Texas Instruments in 1974, and production began in 1981.

The HARPOON began with studies performed in the late 1960s for an air-launched anti-ship missile. These studies culminated in 1971 in a requirement for a weapon that could also be launched by submarine or surface vessel. McDonnell-Douglas was awarded a preliminary development contract in 1971, with a full development contract in 1973, and initial production in 1976. Designated the AGM-84D, it was first introduced into service in 1977. In 1980 an air-launched version was deployed on the Navy's P-3 Orion aircraft. The HARPOON is an all-weather, over-the-horizon, anti-ship missile system. It has a low-level, sea-skimming cruise trajectory, active radar guidance and is a warhead-like design. The first operational version of the HARPOON was for the air-launched version, with ship-launched and submarine-launched versions following. The HARPOON has also been adapted for use on the USAF Air Combat Command's B-52H bombers.[31]

Confronted by the daunting threat of Warsaw Pact capabilities in Europe, the Army initiated several missile programs in the 1970s aimed at defeating both armor and aircraft missiles. In 1976 the General Support Rocket System (GSRS) Project Office was established to begin development of an MLRS system. In 1977 the US Army established the Advanced Heavy Anti-tank Missile Systems (AHAMS) Project Office to develop replacement for the TOW missiles. Another important missile system developed in the 1970s was the AADS-70, later called SAM-D and finally called PATRIOT. With its phased-array radar and ability to simultaneously engage multiple targets, the PATRIOT system had the dual capability against aircraft and ballistic missiles. This system was the successor to the single-kill HERCULES HAWK systems.[32]

Work on a new class of PGM—the terminally guided submunition—began in the early 1970s. The SKEET concept derived from work on smart weapons by AVCO as part of the Air Force Wide Area Anti-Armour Munitions (WAAM) Project. WAAM had the objective of developing munitions that could use IR technology and be fired "blind" into an area and seek out their own targets.[33] SKEET became incorporated into the Sensor Fuzed Weapon (SFD) developed in the 1980s and produced in the 1990s.

In the early 1970s, some highly classified work at DARPA fed into the development of another terminally guided submunition, the Brilliant Anti-armor Munition (BAT). This work was the development of a stealthy "lethal Remotely Piloted Vehicle" by Northrop. Based on the Army-developed AQUILA, this killer RPV concept had acoustic sensors mounted on its wings to detect tanks.[34] While this program floundered, the acoustic sensor capability was maintained and was applied by Northrop when it developed a submunition variant of the Tri Service Standoff Attack Missile (TSSAM), a stealthy cruise missile based on the TACIT BLUE reconnaissance

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31 James Jay Carafano, "Myth of the Silver Bullet: Contrasting Army-Air Force Perspectives 'Smart Weapons' After the 1973 Arab Israeli War and the 1991 Gulf War," *National Security Studies Quarterly*, Winter 1998, pp. 1–20.

32 Redstone Arsenal, Redstone Chrolonogy.

33 Berke, *Smart and Precision Munitions*.

34 See Chapter VI for discussion of UAVs, including AQUILA.

airplane. The TSSAM program eventually was canceled in 1994 when it became apparent that the system had significant development problems and estimates of the unit cost in production had tripled. However, the submunition concept using an acoustic sensor, augmented with infrared for terminal homing, continued and was employed by the BAT (discussed in the next section).

PGM DEVELOPMENTS IN THE 1980s

Science and technology advances in the 1970s, especially in electronics, enabled a "third generation" of PGMs that started to see service in the 1980s. These developments included large-scale integration of microchips (LSI and VLSI), new millimeter wave sources, complex signal processing, on new imaging capabilities, as follows:[35]

1. Microelectronics
   - 1.1 Further advances in VLSI
   - 1.2 Use of advances interconnects in chips
   - 1.3 Improvements in signal integration
2. Computing and data processing
   - 2.1 Use of fiber-optic technology
   - 2.2 Development of fiber optic gyroscope (FOG)
   - 2.3 Development of parallel date processing
   - 2.4 Rapid advancement in high-performance-strategic processing
   - 2.5 Further advances in time sharing systems
   - 2.6 Further advances in interactive computing
3. Lasers
   - 3.1 Commencement of CO2 laser radar
   - 3.2 Laser beam riding systems advances
4. Materials
   - 4.1 Commencement of monolithic ceramic and composite ceramic material development (silicon nitride, silicon carbide)
   - 4.2 Advancement in tailoring materials for structural performances
   - 4.3 Further advances in stealth materials
5. Radar/Sensors
   - 5.1 Use of Forward-Looking Intra Red Sensor (FLIR)
   - 5.2 Use of Laser Detection and Ranging (LADAR) system;
   - 5.3 Low-altitude navigation/targeting infra-red systems (LATRIN)
   - 5.4 Advances in Millimeter Wave Systems (MMW)

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[35] SIA, *The National Technology*; Cook, "War of Extremes." *See also* George and Meridith Friedman, *The Future of War: Power, Technology, and American World Dominance in the Twenty-First Century*, New York: St. Martin's Press, 1996. Richard P. Hallion, *Precision Guided Munitions and the New Era of Warfare*, Paper #53, Fairbairn, Australia: Air Power Studies Centre, 1997. Michael P. Marletto, "The Impact of Emerging Technology on 21st Century Warfare," *Marine Corps Gazette*, 83, January 2000, pp. 27–30. McPeak, Merrill A., "Precision Strike—The Impact on the Battle Space," *Military Technology*, 23:5, 1999, pp. 19–26.

DARPA made significant contributions to advances in several of these technologies.[36] These included TGSM, the sensitive Low Level Laser Sensor System (LLLSS) used in PAVEWAY III and GBU-24 and Thermal Imaging Airborne Laser Designator (TIALD).

Guided Bombs

Incremental improvements were made in guided bombs in the 1980s. Some of these were to accommodate their use in new aircraft, some to improve their ability to hit hardened targets and provide greater standoff range. In this latter regard the AGM-130 was modified from a glide bomb to a rocket-powered system, in effect transforming it into a missile. An interesting development is the modification of the GBU-15 guided bomb into a missile system, the AGM-130A, by employing a rocket motor for extended standoff range and an altimeter for altitude control. The AGM-130A is equipped with either a television or an imaging infrared seeker and data link. The seeker provides the launch aircraft a visual image of the target that is transmitted to the aircraft cockpit monitor. The seeker can be either locked onto the target for automatic weapon guidance or manually steered to the target. The development of the AGM-130A began in 1984.

PAVEWAY III (GBU-24) Low Level Laser Guided Bomb (LLLGB) consists of either a 2,000-pound MK-84 general purpose or a BLU-109 penetrator bomb modified with a PAVEWAY III low-level laser-guided bomb kit. The LLGB was developed in response to improved enemy air defenses, poor visibility, and low ceilings. The weapon is designed for low-altitude delivery with an improved standoff capability of more than 10 nautical miles. The PAVEWAY III also has increased seeker sensitivity and a larger field of regard.

Another guided bomb development was the GBU-27, a 2,200-pound laser-guided bomb designed specifically for use by the F-117 Stealth Fighter. It is a highly accurate, hard-structure munition compatible with the F-117's advanced target acquisition/designator system. The GBU-27 uses a BLU-109 improved performance 2,000-pound bomb developed in 1985 under the project name HAVE VOID, designed for use against hardened structures. The GBU-27 was used extensively during Desert Storm with a claimed hit probability of over 70 percent.

Missiles

Building on an appreciation of the Soviet Union's air defense and its capabilities for attacking ships and armored systems, there was considerable focus in the 1980s by all three

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[36] Richard Van Atta, Seymour Deitchman, and Sidney Reed, *DARPA Technical Accomplishments*, Volume II, Alexandria, VA: Institute for Defense Analyses, July 1991.

Services to obtain standoff capabilities for missiles to strike targets deep into the enemy's territory. The quest for these standoff capabilities created competition among the Services and between rocket-powered guided missiles and cruise missiles.

The Air Force had been pursuing an air-launched deep strike missile, the Conventional Standoff Weapon, in the late 1970s into the early 1980s. Responding to Congressional unhappiness with what it saw as unnecessary duplication and inadequate sharing of technologies between the Army and Air Force in missile programs, the Under Secretary for Defense Research and Engineering directed the Army and the Air Force to integrate their separate programs for standoff missiles in the Joint Tactical Missile System (JTACMS) in 1983.[37] The focus of this system was to be the ability to conduct deep attack of Warsaw Pact second echelon forces. While the alternatives for such a weapon were under consideration, the Air Force terminated its involvement in the joint program in favor of pursuing a Conventional Air-Launched Cruise Missile (CALCM) for its standoff strike capability. The CALCM is a modified Air-Launched Cruise Missile (ALCM) that employs a high explosive, blast-fragmentation warhead, instead of the ALCM's nuclear warhead, and onboard Global Positioning System (GPS) coupled with its Inertial Navigation System (INS) for targeting (replacing the ALCM's TERCOM system). The CALCM became operational in January 1991, at the onset of Operation DESERT STORM.

With the withdrawal of the Air Force, the Army sustained its efforts begun under JTACMS in a new program, the Army Tactical Missile System (ATACMS). A critical factor in the Army's interest in the ATACMS was the ability to launch it from the MLRS.[38] This reduced Army concerns that another launcher would be needed, which would have added to both cost and operational complexity. ATACMS entered full-scale development in 1986, and low-rate production began in 1989. Initial fielding of the ATACMS was in Saudi Arabia in support of Desert Storm, and full rate production began in 1990. As of late 1998, GPS has been the main guidance system for ATACMS.

The Navy approach to a standoff air-to-ground missile in the mid-1980s began with the proven HARPOON. The result was the Standoff Land Attack Missile (SLAM). SLAM is a stretched HARPOON and is classified as a cruise missile. SLAM is directed by a GPS-INS system and uses an infrared imaging system (obtained from the MAVERICK) in conjunction with a video system (obtained from the WALLEYE). SLAM is a command-targeted weapon—

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37 See Chapter IV, "Assault Breaker," for detailed discussion of the origins of ATACMS.

38 There were concerns that the ATACMS would be seen as violating treaties on intermediate range ballistic missiles, so they were designed to fit into the short-range MLRS and disguised as conventional tactical systems (discussion with Gen. Ray Franklin, March 2003).

an operator aboard the aircraft views the infrared image on a TV display and guides the missile to a target. Seven preproduction SLAMs were launched in January 1991 to make strikes on Iraqi targets during the Gulf War. The missile achieved full operational capability in 1993. After the Gulf War, the US Navy decided that it needed a better standoff capability and contracted for an improved SLAM-ER ("ER" for "Enhanced Response") in 1995.

Submunitions

The Sensor Fuzed Weapon (SFW) is an air delivered cluster bomb with terminally guided submunitions employed in a tactical munitions dispenser (TMD) packaged with 10 submunitions.[39] Once a TMD dispenser is released at altitudes from 60 meters to 6 kilometers, a pyrotechnic charge releases the 10 submunitions. Each cylindrical submunition is decelerated by a small parachute that also orients the submunitions vertically over the target area. As the cylinder descends, the four SKEET warheads flip out from the body of the submunitions. Each SKEET warhead is a disk of flat copper backed by an explosive charge that sights its target by a protruding infrared sensor. Once the cylinder is aligned over the target area, the parachute is cut loose and a rocket motor fires to stop the cylinder's fall and start it spinning. Once the cylinder is spinning rapidly, the SKEETS are released in pairs to spin away from the cylinder. They wobble in flight to allow the infrared sensor to scan over the ground below in a spiral pattern. When a SKEET flies over a target vehicle, such as a tank, the warhead's infrared sensor identifies it as a target and fires the explosive charge. This slams the copper plate into the target at about 1,500 KPH, punching through armor and sending splinters through the interior. The infrared sensor is capable of working through the fog, since it is close to the target, and works at night and through electronic countermeasures. (See Figure III-1.)

Further development of the basic SFW, designated the CBU-97, has focused on adding the Wind Corrected Munitions Dispenser (WCMD) inertial-guidance tail kit, resulting in the CBU-105 SFW, to allow medium- to high-altitude delivery and some standoff range for the delivery aircraft. The SKEET submunition is also being implemented as a variant of the Joint Standoff Weapon (JSOW). SFWs are now in the US military's inventory and were used during air strikes during the Kosovo campaign in 1999.[40]

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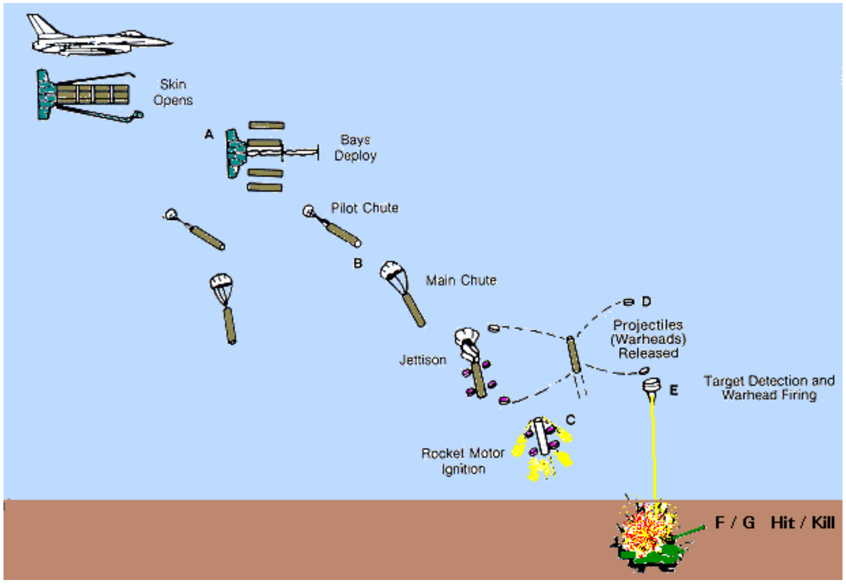
39 *Sensor Fuzed Weapon*, SFW Datasheet, Textron Systems, Wilmington, MA. <http://www.systems.textron.com/pdf/products/sfw_datasheet.pdf>.

40 Birkler, *A Framework for Precision Conventional Strike*.



Source: http://www.fas.org/man/dod-101/sys/dumb/cbu-97.htm

Figure III-1. Sensor Fuzed Weapon Concept of Operations

The Terminally Guided Submunition (TGSM) was developed by the Army for use as the kill mechanism for a standoff anti-armor missile. The TGSM was a miniature, guided projectile that flew directly at the target using its control fins to home in on the target using data from the IR seeker and the guidance system. Each TGSM submunition was equipped with a two-color IR homing seeker, guidance electronics, and a penetrating warhead. The munition was dispensed to autonomously seek out and attack a tank's top armor. The TGSM was then developed further to be integrated into the ATACMS. Early developments of the TGSM by General Dynamics were successfully demonstrated in 1981 and 1982 as part of DARPA's Assault Breaker Program.[41] General Dynamics and Raytheon were awarded contracts in 1988 to develop and test an IR TGSM. The seeker work from Assault Breaker (such as the signal processing logic) was directly integrated into the follow-on TGSM development. The Army did not pursue the acquisition of the TGSM, instead favoring the BAT, discussed below.

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41 Van Atta et al., *DARPA Technical Accomplishments,* Vol. II, p. 5-11.

The Brilliant Anti-armor Munition (BAT) is a cylinder about 1.5 meters (5 feet) long. When released, the BAT pops out four tailfins and four long, straight gliding wings. Its nose contains an infrared sensor, and the wingtips are fitted with long spikes fitted with acoustic sensors derived from an earlier Northrop DARPA program for TSSAM. Once deployed, the BAT glides to a preprogrammed target location and uses the acoustic sensors to identify the general location of a tank. Once the acoustic sensors locate a target, the infrared sensor directs the BAT to hit the target directly from the top, destroying it with a two-stage penetrating warhead. A second-generation BAT with improved seeker system and multimode warhead is being developed as a follow-on improvement.[42]

PGM DEVELOPMENTS IN THE 1990s

In the 1990s the promise of smart munitions was demonstrated in Desert Storm and in the Balkans. The effectiveness of PGMs in the Gulf Wars was primarily the outcome of the use of cruise missiles and the massive use of laser-guided bombs. The outcomes of these conflicts with minimum loss of American lives provided ample argument for the accelerated fielding and development of precision weaponry. The Desert Storm engagement provided the initial operational use of several weapons, such as ATACMS. It also demonstrated that weapons, such as TOMAHAWK, could be used to achieve relatively surgical strikes, therefore supporting the use of PGMs in the new conflict environment where collateral damage is a major concern. Based on this premise, funding for PGM programs was increased significantly.

Over the last decade the use of the GPS has made guided bombs and missiles much more effective for hitting fixed targets. The GPS satellite constellation provided a new guidance option that overcomes some of the limitations of EO and laser guided bombs. With a GPS-INS system, a smart weapon could make precision attacks in any weather, day or night, and at minimal cost. A strike aircraft could acquire targets with advanced all-weather sensors, such as the Synthetic Aperture Radar (SAR), and program GPS-guided weapons to hit individual targets at specific locations. The weapons would proceed to their individual targets without further intervention.

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42 Glen W. Goodman, "Nowhere to Hide: Smart Munitions Rain Certain Destruction from the Sky, *Armed Forces Journal International*, October 1997.

Many of the improvements in the PGMs in the 1990s, in particular in the guidance subsystems, were based on upgrade and advancement of the existing systems as the result of focused preplanned product improvements (PPI) emphasized in the 1970s. Following is a summary of R&D activities undertaken by DoD to enhance US advanced munitions in the 1990s:[43,44,45,46]

1. Microelectronics
   - 1.1 Further reduction of feature size (approaching 0.18–0.15 micro millimeters)
   - 1.2 Increased number of transistors on a chip (7–20M)
   - 1.3 Commencement in use of MEMS technologies
2. Computing and data processing
   - 2.1 Further advances in digital computers
   - 2.2 Further advances in artificial intelligence
   - 2.3 Further advances in density of computing systems
   - 2.4 Advancement in use of computer in internal navigation, PGS, "Referential" navigation, optical version of terrain matching, OTH
3. Materials
   - 3.1 Increased use of graphite in materials (in with aluminum, copper, polymers, carbon)
   - 3.2 Commencement of metal matrix composites (MMCs)
   - 3.3 Advances in radar and IR
4. Propulsion Systems
   - 4.1 Advances in dynamic fuel control and increases in efficient fuel use
   - 4.2 Increases in thrust to weight ratio

Guided Bombs

The Global Positioning System (GPS) is used to aim at fixed targets with known coordinates. The GPS has proven to be a major improvement in the performance of such weapons as glide bombs, since laser-guided bombs are seriously degraded by bad weather, dust, and smoke and require that the target be designated actively, putting the person or system doing the designation at risk. The military has sought a true "fire and forget" guidance system, which could simply receive target coordinates and then destroy the target, and GPS provides such capability.

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43 Mark Hewish, "Kosovo Spurs Precision Bomb Programs," *Jane's International Defense Review*, September 21, 2000.

44 Marletto, "The Impact of Emerging Technology on 21st Century Warfare," *Marine Corps Gazette*, 83.

45 SIA, *The National Technology Roadmap for Semiconductors*.

46 John A. Tirpak, "The State of Precision Engagement," *Air Force Magazine*, 83, July 1999, pp. 24–30.

In the early 1990s, the US military completed the initial deployment of the GPS navigation satellite constellation. The satellites of the GPS network transmit signals that allow a device with a GPS receiver to determine its own location to within a few tens of meters or better. Through GPS a weapon receives coordinates of a target and guides itself to that location. However, since GPS signals can be jammed, GPS-guided munitions usually have a backup INS-based navigation to keep the weapon on course if it can no longer acquire GPS signals. While GPS-INS-based systems are ideal for fixed targets, they do not replace weapons based on EO or laser guidance, or IR and millimeter wave seekers, which have higher precision and are able to attack mobile targets whose coordinates cannot be easily determined in advance.

After the Gulf War, the frustration of being unable to hit targets, due to bad weather, led the USAF to develop a GPS-guided bomb, the Joint Direct Attack Munition (JDAM), as a precision weapon for the B-2 stealth bomber. JDAM was scheduled to become available late in the decade, however, so Northrop Grumman proposed a "fast-track" program to provide a GPS-Aided Munition (GAM) until JDAM development. The resulting weapon, the GAM-84, was demonstrated in October 1996.

JDAM is designed to provide the same capabilities as GAM, but at low cost in high volume for use on several different aircraft. The JDAM is a tail kit with a GPS-INS guidance system that is strapped on to the bomb. Kits are now available for a wide range of bombs. First tests of JDAM were performed in late 1996, and the weapon has been evaluated on most US attack aircraft. JDAM was first used in combat during the Kosovo campaign in 1999, which was also the first combat use of the B-2.

The Wind Corrected Munitions Dispenser (WCMD) is a kit for glide bombs that use an INS guidance system but have no GPS capability. Unguided cluster bomb units have to be released from low altitude to keep them from being blown off target by the wind. Adding a guidance system permits such munitions to be dropped from high altitude, but then wind is a factor in their accuracy. WCMD employs INS to provide acceptable accuracy for a wide-area weapon, such as a cluster bomb unit, and GPS was not regarded as necessary. The WCMD consists of a tail-kit that can be attached to a Tactical Munitions Dispenser (TMD). The WCMD is used with TMDs employing Combined Effects Munitions, mines or the Sensor Fuzed Weapon. The WCMD kit is now in full production.

The US Navy and Air Force "Joint Standoff Weapon" (JSOW) is an unpowered glide bomb that uses a GPS-INS navigation system to attack targets at greater ranges. JSOW is designed to fly a preplanned path to its target. The first version of JSOW to be developed was the AGM-154A, which carries combined-effects submunitions for use on "soft" targets. Another version of the JSOW carries six SFW submunitions. JSOW was introduced to combat in January 1999, during air strikes by US Navy strike aircraft on Iraqi air-defense sites.

Missiles

The US military recurringly has pursued a standoff weapon with greater range to allow attacks into areas protected by long-range surface and air missiles. The origins of the JASSM may be traced to the late 1970s when the Air Force turned to a cruise missile instead of participating in the JTACMS missile. The cruise missile program became the Tri-Service Standoff Attack Missile (TSSAM), which was subsequently canceled because of technical difficulties and cost increases on the order of threefold. In 1996 the AGM-158A Joint Air to Surface Standoff Missile (JASSM) was initiated. The emphasis in JASSM development is to limit costs while retaining capability. Price is expected to be under $500,000 in quantity, whereas the TASSM was targeted at $750,000 and was estimated to have increased to over $2 million per unit. JASSM is a cruise missile powered by a turbojet engine and is to be highly stealthy. JASSM navigates using a GPS-INS guidance system and has infrared seeker system. Lockheed Martin won the full-scale development contract in 1998. JASSM is completing the Engineering, Manufacturing and Development phase and has moved to Low Rate Initial Production.[47]

The USAF has been working on a smarter submunition, named the Low Cost Autonomous Attack System (LOCAAS). LOCAAS is intended to fly into a target area, search for targets, and destroy them. Both glider and jet-powered versions have been investigated, though it appears that the powered version, P-LOCAAS, is now being emphasized. The submunition navigates with a GPS-INS guidance system.[48] LOCAAS submunitions are carried in a TMD containing either six glider submunitions or four jet submunitions. Four such dispensers can be carried on an F-16 or F-22 strike fighter, for a total of 16 P-LOCAAS submunitions. It could also be launched into a target area by missiles. The weapon carries a laser seeker that sweeps the target area underneath. The seeker is coupled to a target-recognition system that compares target features with a library of possible targets and prioritizes them for attack. LOCAAS can be programmed before launch to target specific target types. An explosively formed projectile, similar to but more sophisticated than that fired by the SKEET warhead used in the SFW, performs the actual attack. The copper slab in the “multimode” warhead is backed by explosives that can be fired in sequence to either spray the copper in pellets

47 Air Force Materiel Command, Press Release, 2002.

48 Cook, “War of Extremes.”

(to attack soft targets like trucks), to wad the copper into a slug (to attack light armored vehicles), or form it into a rod (for attacking very hard targets). LOCAAS is an experimental project at present, as its technologies are very advanced and will need considerable effort to get to work reliably, much less build them at low cost. It is not envisioned as being available for operations before 2007.

CONCLUSIONS

The development and use of increasingly precise guided weapons for tactical standoff strike has provided US forces with abilities to attack and eliminate more difficult targets from greater distances with increasing probability of kill. These capabilities have been instrumental in transforming strategy, both during the Cold War, during the Gulf War, and more recently, as the US has had to contend with dispersed and elusive foes. The bulk of the munitions employed have been older bombs upgraded with sensors and designators to provide them increased accuracy. At the same time newer weapons, based on DARPA-developed concepts that sought to negate Soviet forces during the Cold War, began to be deployed and used. But the emergence of smart precision-guided weapons, such as terminally guided submunitions, has been slow.

A range of capabilities for attacking targets from great distances with great accuracy has been demonstrated. What is apparent is that alternative and competing approaches have vied with one another on the one hand and have increasingly merged into hybrid systems that are rendering moot earlier distinctions among formerly highly differentiated approaches. The trend is toward multiple sensing and guidance modes to find, discriminate, and precisely hit targets. At the same time the targets of interest are becoming increasingly challenging, as adversaries become aware of the devastating capabilities of US standoff strike weapons against stationary and massed targets. Finding and hitting elusive targets in complex terrain has become the major challenge for future precision weapons developments. Precision effects—achieving the conflict objective with minimal collateral damage in complex environment—is another driver of future developments as US forces are likely to face conflicts in areas where enemies are intermingled with noncombatants.

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IV. ASSAULT BREAKER

Richard H. Van Atta, Jack Nunn and Alethia Cook

OVERVIEW

The DARPA Assault Breaker program was established in FY 1978 by then Under Secretary for Defense Research and Engineering William Perry. The program responded to two important trends. One was the nature of the evolving Soviet conventional threat in Europe and the realization that the timely use of tactical nuclear weapons to stop an attack in that theater was unrealistic. The second trend was technological developments in sensors, delivery systems and conventional munitions that had the potential to greatly mitigate or potentially negate the Soviet threat and to do so without resort to the use of nuclear weapons.

The Assault Breaker Program was one of several DARPA initiatives undertaken at that time to leverage prior R&D expenditures to meet the emerging Soviet military capabilities. A review of programs being pursued within the Services indicated that selectively combining technologies might significantly multiply the effectiveness of US forces against those of the Warsaw Pact. Testifying before Congress, Dr. Perry stated his belief that precision guided weapons represented "…our greatest single potential for force multiplication."[1] He went on to testify that:

> Precision guided weapons, I believe, have the potential of revolutionizing warfare. More importantly, if we effectively exploit the lead we have in this field, we can greatly enhance our ability to deter war without having to compete tank for tank, missile for missile with the Soviet Union. We will effectively shift the competition to a technological area where we have a fundamental long-term advantage.[2]
>
> Summarizing the reasons for the drive toward precision, Perry stated:
>
> In sum, the objective of our precision guided weapon systems is to give us the following capabilities: to be able to see all high value targets on the battlefield at any time; to be able to make a direct hit on any target we can see, and to be able to destroy any target we can hit. We are converging very rapidly on these objectives. We are developing tactical systems—bombs and missiles—to help offset the numerical superiority we face today in NATO. We are developing strategic

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1 William J. Perry testimony, US Congress, Senate Committee on Armed Services, Department of Defense Authorization for Appropriations for FY 79. Part 8: Research and Development, February 28, March 7, 9, 14, 16, 21, 1978, pp. 5506–5937.

2 Ibid., p. 5599.

> systems—cruise missiles—to help maintain our position of strategic equivalence in the next decade. Taken in aggregate, precision guided systems can make a significant contribution to our ability to deter war. They exploit technologies in which the US leads the world; they are "force multipliers"—that is, they produce a greatly increased force effectiveness with a moderate investment; and they make maximum use of equipment—artillery pieces and tactical aircraft—already deployed.

The Assault Breaker Program was designed to help test this concept at the tactical level and to demonstrate the potential of many of the technologies that were already being developed. Although the efforts to pursue the promise of precision strike have sometimes flagged over the intervening years, Dr. Perry's statement of what precision strike should do: e.g., "see all high value targets," "make a direct hit on any target we can see," and "destroy any target we can hit," have continued to be the driving objectives of the American effort toward long-range precision strike. Many of these efforts are now coming to fruition.

BACKGROUND

The Soviet military posture in Europe worried American security planners throughout the 1970s. Soviet strategic nuclear forces had reached a level that made escalation from a tactical nuclear war in Europe much more likely. Moreover, even if nuclear war might be confined to a European battlefield and strategic nuclear exchanges might somehow be avoided, it was increasingly difficult to envision any set of circumstances in which the European NATO nations would authorize the use of tactical nuclear weapons early enough to prevent a rupture of NATO's forward defenses. Coupled with the Soviet Union's strategic force developments, Warsaw Pact conventional forces were also being rapidly modernized. Dr. Malcolm Currie detailed the trends in Soviet conventional force modernization in testimony in 1976. He reported that the worrisome new Soviet capabilities that faced NATO included:

> Impressive new armored fighting vehicles, tanks and armored personnel carriers, each with new guns, night vision devices and protective systems for operating in war involving chemical, biological and radiological munitions.
>
> Improved artillery—greater range and firepower than our own—rapid-fire rocket launchers and mine-laying systems, all massively produced and providing, in total, an unprecedented suppression capability.
>
> A fundamental change in Soviet threat aircraft ground attack capability—a fourfold increase in payload and a two-and-one half increase in range.[3]

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[3] Dr. Malcolm Currie testimony, US Congress, Senate Committee on Appropriations, Department of Defense Appropriations for FY 77, Hearing, February 3, 17, March 16, 18, 23, 31, 1976, pp. 888–889.

Currie ascribed these Soviet developments to a steady research and development effort by the Soviets, combined with production of the fruits of that research. If this trend continued without a US response, he told the Congress, it could lead to "dominance by the Soviet Union in deployed military technology in a decade."[4] But he said that this would not be the case if the US continued to maintain a strong military R&D program. In subsequent testimony, Dr. Currie and Dr. George H. Heilmeier, the Director of DARPA, outlined the DoD's plan for responding to these Soviet advances.

DEVELOPING AN R&D RESPONSE STRATEGY

The defense R&D situation in the early 1970s, as described by those interviewed for this study, and depicted in Congressional testimony at the time, is one of too many programs, each with too little funding and a general lack of priorities. Those interviewed agreed that there was a need to identify what worked and prioritize the US technology effort. Dr. Currie's Congressional testimony reveals an effort to organize and set priorities. In shaping the US R&D response to the Soviet buildup, he told Congress that the DoD proposed to invest $4.2 billion, or almost 40 percent of the FY 1977 RDT&E request, on tactical warfare programs. He said that the program reflected a transformation occurring in military technology. The new technologies being developed would change concepts and capabilities in command and control, mobility, armor/anti-armor, night fighting, massed firepower and the precision application of force at a distance. He noted that one of the two principal threats against which these tactical developments were focused was a "breakthrough 'blitzkrieg' campaign by the Warsaw Pact in NATO's central region involving unprecedented massed armored forces and firepower."[5] There was thus a clearly identified threat against which this tactical R&D needed to be directed. But there were also other competing threats; such as the enhanced Soviet tactical air forces and their greatly improved air defense capability, as well as the growing Soviet Navy. For Dr. Currie and others who were trying to develop an overall plan to respond to Soviet developments, there were more than enough threats and needs for the money available. Moreover, rationalizing the many on-going Service R&D initiatives aimed at dealing with Service specific aspects of these tactical threats presented additional challenges.

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4 Ibid., p. 889.

5 Ibid., p. 896.

DARPA'S ROLE IN THE STRATEGY

Testifying at the same hearing in 1976, the DARPA Director, Dr. Heilmeier, outlined the Agency's role in the on-going research effort. As a part of his discussion of the role and mission of DARPA, Dr. Heilmeier outlined a defense R&D investment strategy for the late 1970s. He stated that an investment strategy involves "carefully balancing technology assessments, projections, initiatives and opportunities against potential mission initiatives and needs."[6] He stated that a defense R&D investment strategy was essential for several reasons.

> First, the keystone of our efforts must be selectivity. We simply cannot afford to follow all possible paths and single-handedly support all the worthwhile science and technology in the country.
>
> Second, the lead-time for research and development is typically more than four years while the budgetary process, which is structured around operational considerations, tends to focus incrementally on a year at a time.
>
> Finally, our competitor, the Soviet Union, has a solid appreciation and long-range commitment to military-related advanced technology. This commitment, coupled with their extreme secrecy and the fact that we no longer hold a monopoly on advanced technology, presents a free society with the challenge to view defense related technology from a comprehensive, long-term standpoint.[7]

Dr. Heilmeier testified that within any DoD investment strategy, DARPA played the role of the corporate research capability that might be found in a large commercial company. He said that just as in private corporations, it is essential for the DoD to have an effective central research activity with the flexibility to move rapidly into new areas to explore new opportunities and that reports to the very top of the organization. DARPA had to help generate options and avoid technological surprise. The organization had to have no vested interest in the status quo, nor be encumbered by current roles and missions. It also had to be able to explore new ideas and concepts without preordaining a commitment to go into full-scale development even if the concept proves workable. In considering his testimony, it appears that DARPA, as a small and diversified organization was ideal for managing a proof of concept for a technological solution to a problem that ran across Service lines such as the Soviet breakthrough threat in Europe.[8]

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6 Ibid., p. 926.

7 Ibid.

8 Ibid.

Technology Initiatives Leading Up to Assault Breaker

The concern over the Soviet conventional threat in Europe continued to grow in the mid-1970s. There were a number of technological initiatives aimed at dealing with elements of this growing threat. Many of these initiatives were seeking capabilities that were related to the precision objectives that Dr. Perry provided Congress in 1978. For example, the Air Force was developing and deploying the Airborne Warning and Control System (AWACS) to detect low-flying Soviet aircraft. Engineering, test and evaluation began on the first E-3 Sentry in October 1975 and the first E-3s were delivered to the 552nd Airborne Warning and Control Wing in March 1977. Air Force personnel demonstrating the aircraft in Europe noted its capability against moving ground targets (autobahn traffic) as well as aircraft.[9] This concept was later pursued by the Air Force in the mid-1970s. For long range battlefield surveillance the Air Force was developing the high altitude TR-1 that was to carry the synthetic aperture radar (SAR).[10] In the mid-1970s, DARPA pursued the concept of modifying the Air Force developed SAR to obtain MTI (moving target indicator) capability. This effort later became the joint DARPA-Air Force Tactical Air Weapons Direction System (TAWDS) project.[11] TAWDS itself was subsequently renamed Pave Mover.[12] Using the radar developed under this program, ground targets could be identified and tracked and a missile guided to attack mobile targets. Pave Mover subsequently became a part of the Assault Breaker Program.

The Army was also working on its own airborne, ground targeting system: the Stand Off Target Acquisition System (SOTAS) carried on a helicopter. SOTAS was advertised to Congress as "in some ways a small version of AWACS."[13] The moving target indicator (MTI) radar relayed enemy vehicle movements back to Army ground stations. Both the Air Force and DARPA also became involved in the SOTAS effort. The Army also continued to work on unattended ground sensors such as those used earlier in Vietnam. These could be delivered by hand, artillery, or air and could supply sensor information on likely enemy approaches.[14] The Army, as well as DARPA was also interested in remotely piloted vehicles (RPV) as another

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9 Interview with General William Creech, USAF (Ret)

10 Richard Van Atta et al., *DARPA Technical Accomplishments,* Vol. II, Alexandria, VA: Institute for Defense Analyses, April 1991, p. 5–6.

11 Ibid.

12 Ibid.

13 Dr. William Perry testimony, US Congress, Senate Committee on Armed Services, Department of Defense Authorization for Appropriations for FY 79. Part 8: Research and Development, February 28, March 7, 9, 14, 16, 21, 1978, p. 5993.

14 Ibid.

means to observe behind enemy lines. RPV of the time could carry TV cameras and when fitted with a laser designator, could guide munitions onto moving targets such as tanks.

Both Services were also pressing ahead with separate efforts to develop new munitions to destroy hardened and mobile ground targets during this period. Not surprisingly, the Air Force was exploring ways to deliver such munitions from the air, while the Army was looking at both ground and helicopter delivery systems. The Air Force was developing improved laser bombs and experimenting with cruise missiles. The Army was developing a non-nuclear Lance missile, the General Support Rocket System (which ultimately became the Multiple Launch Rocket System—MRLS) and other Corps Support Weapons System options.

The two Services were also working on numerous munitions projects aimed at developing munitions that could be used against hardened, mobile targets. The Air Force had an on-going wide area anti-armor munitions (WAAM) project. This project included submunition such as the WASP, a small, high velocity air launched missile, and SKEET, a self-forging fragmentation munitions developed by AVCO. The Army was developing a Terminally Guided Sub-Munition (TGSM) for its tube artillery and rocket systems.

DARPA was involved in a number of specific studies that had an effect on the shape of the DoD long-range precision strike developments. Robert Moore, the Deputy Director of DARPA's Tactical Technology Office (TTO) in the early 1970s, stated that his office was receiving increasing amounts of information on the Soviet tank threats in Europe and ways to deal with it, and that the TTO was involved in a number of initiatives. For example, Moore was receiving regular intelligence briefings on the growing Soviet threat as well as periodic briefings from industry personnel working on studies for the Defense Nuclear Agency (DNA).[15] In 1975, Leland Strom—a radar expert and program manager on the DARPA/TTO staff—came to Moore with the concept of using an MTI (Moving Target Indicator) radar to track a missile to a ground target (e.g., a group of tanks), "close the loop" to guide it to the target and use terminally guided submunitions for the endgame. It was concluded that attacking tanks in this manner would introduce an approach akin to that used in air defense where tracking, targeting and missile guidance had to be closely-coupled in order to engage and hit the incoming aircraft. They

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15 Interview with Robert Moore.

believed that such an approach, if developed, would obviate the need to wait until the tanks were in line-of-sight when a US (NATO) company would be facing a Warsaw Pact battalion with at least 3:1 disadvantage.[16]

About this same time, Mr. Moore received an industry briefing from Mr. Robert Whalen of Martin Marietta in Orlando outlining a battlefield interdiction missile system that would employ the Patriot missile (T-16) with terminally guided submunitions using electro-optical seekers (these had their origins in DARPA's CLGP/TLGP program which had spawned the SAL seeker concept for Cooperhead).[17] There appears to have been considerable interaction among many groups working on these issues. For example, Whalen was a member of an NSA steering committee and had been exposed to a study by Don Latham (then a NSA employee) entitled "*SIGINT Support to the Battlefield Commander*". That study illustrated the need for correlation and fusion, as well as a long-range precision strike capability against tanks.

Based on the statement of the problem and these initial concepts for meeting it, Moore asked Lincoln Laboratory to do a study of an "Integrated Target Acquisition and Strike System" (ITASS). Dr. Larry Lynn headed this study. DARPA defined the general concept and asked Lincoln Laboratory to flesh it out down to actual systems to be used, the enabling technology and to evaluate technical feasibility. In interviews, Mr. Moore reported that even at this early juncture this was an explicitly joint concept (linking Army and Air Force). The original concept included an air-launched missile option using a T-16 launched from an F-16. (This was seen as a necessary option to guard against the Soviets making an end run through Northern Germany rather than attacking through the Fulda Gap.) The ideas contained in this study were briefed in the next DARPA budget review, and funds were requested to begin this program, but it was not initially funded. There were concerns within DARPA that the effort was not really developing advanced technology but was instead integrating existing or relatively near-term technology. Moreover, the program involved major systems development (systems of systems) that would entail a large percentage of DARPA's available investment funds.

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16 Ibid. In 1974 DARPA's TTO had studied the notion of Distributed Area Defense (DAD) under then Colonel Ray Franklin, as a concept for attacking Soviet armor in a three-tiered approach, including the use of long-range missiles with submunitions guided by MTI radar. (Discussion with General Ray Franklin, USMC (Ret.), March 2003.)

17 Ibid.

Some of the many technology developments that were on-going at this time are grouped below according to Dr. Perry's categories.

- *See all high value targets on the battlefield at any time*
    - Airborne Warning and Control System (AWACS)
        - APY-1 radar
    - Pave Mover
        - Synthetic Aperture Radar
    - Stand-Off Target Acquisition System (SOTAS)
        - Moving Target Indicator
    - Remotely Piloted Vehicles (RPV) and Mini-RPV
        - TV and laser designators
    - Unattended Ground Sensors (Remotely Monitored Battlefield Sensor System (REMBASS)
        - Acoustic sensors
- *Make a direct hit on any target we can see*
    - Army's non-Nuclear LANCE
        - Directional Control Automatic Meteorological (DCAM) Compensation guidance
    - Army's Patriot Missile
        - Modification of the T-16 Bus
    - General Support Rocket System
        - MLRS
    - Aircraft
        - Air Force Medium Range air-to-surface missile (MRASM)
        - Smart bombs
- *Destroy any target we can hit*
    - Rockeye bomb
        - Loaded with unguided anti-armor shaped-charge bomblets
        - KB-44 bomblets
    - Wide Area Anti-Armor Munitions (WAAM)
        - SKEET
        - WASP
    - Conventional Lance/Artillery
        - Terminally Guided Submunitions (TGSM)—IR or Millimeter-wave guided

To be successful, an R&D investment strategy such as Assault Breaker, which aimed at evaluating a number of different technology alternatives for attacking an enemy ground threat, would have to take into account these various Service efforts and deal with them as a part of the rationalization of the overall R&D investment effort.

Growing Support for a Coordinated Program

The 1976 DSB Summer Study focused on meeting the Warsaw Pact threat with conventional weapons.[18] It reviewed many of the developing technologies cited above. The Panel members included a number of people who had been involved in studying the US response to the growing Soviet threat including: Robert Whalen, Joe Braddock, and Don Latham. Martin Marietta's Battlefield Interdiction Missile was presented as one of the possible alternatives. The DSB report gave strong backing to the ITASS concept that had been detailed by Lincoln Laboratory. It concluded that some of the technologies, or achievable modifications of them, could be integrated into a feasible fighting system that could effectively counter the second echelon of a Warsaw Pact attack in Europe. It noted that there had been no organized attempt to put the technologies together and test the concept. The Panel reported that some of these approaches would require an unprecedented degree of interdependency of Army and Air Force operations, and unprecedented degree of coordination and timing in actual operational execution on the battlefield, and that all this posed not only severe technological challenges, but also many doctrinal challenges.[19] Because of the strong interdependency required, the Panel recommended that a special management scheme be developed.

During this same timeframe, there were a number of on-going studies on the use of enhanced radiation weapons (neutron bombs) in Europe. Lance missiles and eight-inch howitzers could deliver these weapons. The combination of these smaller weapons and their greater accuracy (possibly as a result of cruise missile developments) promised to deal with the massed Warsaw Pact tank forces. Some of these studies were briefed to General Donn Starry, the new commander of the Army Training and Doctrine Command (TRADOC). General Starry, who had recently commanded troops in Europe, was impressed by the briefings, but his recent experience in Europe made him skeptical about the early use of nuclear weapons. However, he drew the conclusion that the accuracy of the new weapons made it possible to use conventional

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18 Defense Science Board, *Summer Study on Conventional Counterforce Against a PACT Attack*, Final Report, Washington, DC: Office of the Secretary of Defense, 1976.

19 Richard Van Atta et al., *DARPA Technical Accomplishments,* Vol. II, pp. 5-5 and 5-6.

weapons to attack the Warsaw Pact tank threats.[20] He was therefore receptive to developments of conventional attack capabilities. Moreover, the commander of the Air Force Tactical Command, General William Creech, had recent European experience with the AWACS and the potential for air surveillance of ground targets and was supportive of working cooperatively with General Starry to deal with the tank threat in Europe.[21] Thus there was support from the major commands of the two Services that might be involved in a cooperative technology development against the tank threat. However, such support appears to have been limited. Both Services had many additional technology requirements on their individual agenda. The Army, for example, was deploying the M1A1 tank and working on the M1A2. The Air Force was deploying both the F-15 and F-16 fighters and developing upgrades. New systems that might detract from these developments would be unlikely to get the highest Service priority. On the other hand, the Army was very interested in developing a new Corps Support Missile System. It should have come as no surprise then that the Army would prove to be more supportive of the subsequent Assault Breaker missile development than was the Air Force. As one participant noted, the DARPA development with the Army proved successful because it was indeed in line with something the Army wanted to do.[22]

Establishing the Assault Breaker Program

Although congressional testimony indicates that Dr. Currie began to set priorities on the necessary research developments in 1975, and DARPA under Dr. Heilmeier had begun to focus some of the Agency's efforts on the Soviet tank threat, the development of a focused program did not occur until May 1978 when new DARPA Director Robert Fossum agreed to fund the program. Some of this delay in establishing the Assault Breaker program was the result of the change in administrations and the associated time required to organize a new group of policy-makers.[23] Fossum had concerns that the Assault Breaker system was "fragile"—it linked together multiple capabilities the robustness of which in a combat environment was unproven and thus introduced considerable operational uncertainty. On the other hand he appreciated that Assault Breaker represented a potential step-level improvement in capabilities to redress the Soviet conventional threat—and therefore approved the program.[24]

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[20] Interview with General Donn Starry, US Army (Ret).

[21] Ibid., and Creech interview.

[22] Interview with General Donald Keith, US Army (Ret).

[23] Interview with Robert Moore.

[24] Interview with Robert Fossum.

Assault Breaker was part of a broader integrated concept that included DARPA's Battlefield Exploitation and Target Acquisition (BETA) and Coherent Emitter Location Testbed (CELT) programs. In 1977, DARPA had established the related technology development demonstration: the BETA project. BETA was aimed at demonstrating the feasibility of a state-of-the-art, computer-based tactical data fusion system facility capable of dealing, in near real-time, with the large amounts of information on the modern battlefield.[25] This program began in response to concerns expressed by then DDR&E Malcolm Currie (stemming from his Chairmanship of the Intelligence R&D Committee) that there was no adequate mechanism for correlating and fusing the extensive intelligence information being received from multiple sources. A review of the issue found more than 50 studies on this problem recommending various approaches and expressing concerns over various possible drawbacks, but that there had been no systematic approach to develop and evaluate capabilities to actually do it.[26] At the same time, a JCS group was trying to develop requirements and grappling with the question of what correlation and fusion would contribute—what its value might be. The decision was made to conduct an experiment to attempt to correlate and fuse intelligence data in the next REFORGER (Return of Forces to Germany) Exercise—a large exercise involving several hundred thousand troops conducted every fall and including two-sided field combat exercises. The objective would be to see what value such information might provide. The concept was to take intelligence on the battlefield from multiple sensor inputs on target reports (the classification of the target, why it was classified, its time and location) and look for correspondence among the reports to better determine possible targets for engagement. BETA was to combine data from:

- Synthetic Aperture Radar (SAR) from ASARS on a TR-1
- SOTAS-Moving Target Indicator (MTI) using an advanced helicopter-based testbed
- Emitter locator (based on earlier Air Force work on PLSS—CELT was not available until later. It was planned to use the prototype PELS Precision Emitter Location System.)
- COMINT input from GUARDRAIL
- ELINT from Quick Look
- HOstile Weapon Location System (HOWLS) including acoustic arrays, UAV radar when it became available later and the Army projectile tracking radars TPQ-36, or TPQ-37.[27]

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25 Richard Van Atta et al., *DARPA Technical Accomplishments,* Vol. II, pp. 6-1 to 6-11.

26 Interview with Robert Moore.

27 Ibid.

The BETA project was managed through an Army executive agent who functioned as part of the DARPA staff. A key issue for the experiment was that the Army and Air Force had different requirements for sensor input and correlation and were trying to get their respective needs built in, while DARPA believed what was needed was sufficient sensor coverage to do an experiment. DARPA planners were also concerned that "requirements creep" not overwhelm the experiment.[28]

Another related development, CELT was tested in NATO exercises in 1978–80. CELT was aimed at developing an automatic, near real-time system for precision location of communications emitters. The technology grew out of extensive research in the 1960s and early 1970s. It provided another targeting means for the Services, and both the Air Force and the Army were interested.[29] These two projects were planned to be closely coordinated with Assault Breaker, but the timelines of the three different projects never allowed them to be fully coordinated. However, all three of the projects were subsequently seen as having significant positive impact on the development of a coordinated response to the European tank threat and similar threats.[30] DARPA was given management responsibility for the Assault Breaker Program. DARPA managed the BETA program through the Army and the CELT program was managed by DARPA.

It is obvious from the earlier discussion that there was significant activity on elements of the technology to deal with the Soviet tank threat in Europe prior to Dr. Perry's appointment as Under Secretary, but several of those interviewed indicated that he was critical to forging ahead with programs aimed at precision attack. Participants indicated that Dr. Perry had a great ability to cut through hard problems, identify needs and potential, and to set priorities. As one interviewee put it, Dr. Perry "had a great ability to leverage previous technology investments to meet defense needs." With so many contending programs on-going, it was essential to do just that if the DoD's need for precision attack was going to be adequately addressed.

Program Management

The Assault Breaker program manager at DARPA had the Air Force Electronics Systems Division as agent for the radar Fire Control Center and the system integration, with technical support from Rome Air Development Center. The Army's Missile Research and Development Command (MIRADCOM) was responsible for the surface-to-surface weapon including sub-

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28 Ibid.

29 Richard Van Atta et al., *DARPA Technical Accomplishments,* Vol. II, pp. 7-1 to 7-7.

30 Ibid.

munitions and the bus.[31] Dr. Fossum testified to Congress that a Steering Group was established "to insure that this rapidly moving program doesn't stumble, should a decision to inventory be made by the services after the demonstration has been successful, assuming success."[32] He reported that the Steering Committee's principal "purpose is to plan for the transition; to make a development plan; and to generate and staff the mission element need statement that is required. …. A second purpose is to insure that the services have it at a reasonably high level, [and have] adequate input into the technical and military specifications of the system demonstration to insure we have not left anything out."[33] Dr. Fossum estimated that the demonstration would be completed in 1981.

Dr. Fossum noted that any decision to procure some of the developing technology was a Service, not a DARPA decision. To help coordinate the program at the highest Service levels, Dr. Perry had also established an Executive Committee composed of the three Service R&D Secretaries. The Deputy Under Secretary for Tactical Warfare Programs (Robert Moore, who had been brought into DDR&E by Dr. Perry) served as the Committee Secretary. Dr. Perry also received input from general officers from the Services' Systems Command and Development Command and from TRADOC and the Tactical Air Command. Representatives from TRADOC and Tactical Air Command were also on the Steering Committee.[34]

Although the demonstration was run effectively, the concern over the transition to fielded systems (voiced by Dr. Fossum in his testimony) proved well-founded. It was difficult to obtain and keep the Services' support for joint programs that might leave either one dependent on the other. Consequently the subsequent efforts to transition to a fielded system were a disappointment. In practice a jointly developed technology was usually transitioned to the Services and went into single Service systems, but these systems had to compete directly with other Service priorities for scarce funding.

Even in the case of the Pave Mover ground surveillance system where there was cooperative Service support flowing from commonality of views between TRADOC and Tactical Air Command, a deployed system took more than a decade and then occurred because of the requirements of the Gulf War. Other Service priorities simply overshadowed these developments and their potential. However, despite the shortcomings of the management scheme, the clear

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31 US Congress, Committee on Armed Services, House of Representatives, 96th Congress, 1st Session Hearings on Military Posture and HR 1872, R&D, p. 913.

32 Ibid.

33 Ibid.

34 Ibid.

consensus is that some high level joint management scheme is essential to deal with the development of new concepts that cross the lines of traditional Service roles and missions and might challenge currently deployed weapon systems. This is a topic that demands much more study and consideration since it gets to the heart of the issue of transitioning technology into operationally fielded systems.

Program Concept and Structure

The Assault Breaker Program was designed to test a concept, not a particular system. The question to be answered by the test was whether the developments in sensors, computing, communications, guidance and munitions allowed for deep precision attack against hard, mobile targets. To be sure, individual systems and components were tested, but these were as a part of an overall prototype system, rather than tests leading to individual system deployment. In this case the munitions were delivered by a ground-launched system, but air-launched missiles were also considered. What type of air delivery (ballistic or cruise) might occur was a source of controversy within the Air Force technical community. Reportedly many in the Air Force ammunition community opposed the use of air-launched ballistic missiles. Ultimately cruise missiles won out.

In the Assault Breaker concept the target was to be detected and located for attack by airborne radar operating at some distance from the front line. Information on the target would then be passed to an "attack coordination center" (also a part of the Assault Breaker development and evaluation process). This data "fusion" processed the radar information and coordinated it with information available from other sources.[35] Since some of the expected targets were mobile, a rapid decision was necessary from the coordination center. Either a ground, or air-based missile was fired, initially guided by its own inertial guidance, but later given a guidance update by the Pave Mover aircraft. The Pave Mover would then guide the missile to a target area where submunitions were released to home on the targets. The submunitions dispersal pattern could be controlled to match the expected target distribution. Submunitions had to be able to recognize the target and home in on it. They used either IR or millimeter wave sensors and either hit the target directly (TGSM) or fired a penetrating pellet against it (SKEET).[36] Many of the elements of this concept of attack on the Soviet threat had been discussed. Indeed that is why the

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35 Early congressional testimony also combined the Battlefield Exploitation and Target Acquisition (BETA) test bed with the Assault Breaker. This fusion of information sources was essential to battlefield success.

36 Richard Van Atta et al., pp. 5-8 and 5-9; and US Congress, US Senate Subcommittee on Research and Development, Committee on Armed Services, Department of Defense Authorization for Fiscal Year 1980, Technology Base DARPA R.D.T.& E., pp. 2886 and 2887.

airborne radar and the submunitions were being developed by the Services. However, the Assault Breaker program was the first time that the elements had been assembled and tried as a comprehensive system.[37] The plan initially envisioned including the BETA and CELT efforts, but because of the press of time, these were never integrated into the Assault Breaker Program.

The testing program was divided into four phases.

- **Phase I** focused on verifying that essential component technologies were really available and that their performance estimates added up to a feasible overall concept.
- **Phase II** involved testing most of the critical component technologies and making further developments as necessary. These were conducted in parallel to save time.
- **Phase III** involved the testing of gradually more complex degrees of systems integration.
- **Phase IV** involved testing the combined airborne radar-missile-submunitions against some stationary tank targets at White Sands Missile Range.

There was reportedly a "Service coolness" to the Program. Congress, expressing concern over management, initially withheld funds for the Program from the FY 1979 budget.[38] However, in order to get started, DARPA used internal funds to begin the testing process.[39] Verification of component technologies took place in FY 1978; the testing of other critical components and some development occurred in FY 1979 and 1980. More complex testing started in FY 1980, and the combined testing of airborne radar and submunitions occurred in FY 1982 and 1983. Steering Group meetings were scheduled periodically and in addition, Dr. Perry met separately with senior Service representatives.[40]

The Program was established with the idea of having performance competition at all levels where it was possible. There were at least two contractors involved in all the major tests and developments. For example, Hughes and Norden each supplied technology for the Pave Mover radar system and related ground-processing stations. There were also two missile contractors working on delivery systems: Martin provided the Patriot T16 (this consisted of the Patriot booster and its autopilot),[41] and LTV provided the Lance T22 booster.[42] In the area of

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37 Richard Van Atta et al., *DARPA Technical Accomplishments*, Vol. II, p. 5-9.

38 Ibid., pp. 5-6 and 5-7.

39 Interview with Robert Moore.

40 Interviews with General Donn Starry and General William Creech.

41 US Congress, US House of Representatives, Committee on Armed Services, Hearings on Military Posture and H.R. 1872, DoD Authorization for Appropriations for Fiscal Year 1980. Part 3, Book 1 of Research and Development, p. 910.

42 Richard Van Atta et al., *DARPA Technical Accomplishments*, Vol. II, p. 5-9.

submunitions, AVCO, as noted previously, was working on the SKEET and General Dynamics was working on the Terminally Guided Submunitions (TGSM).[43] The submunitions were tested individually with emphasis on the required dispersing and homing properties of the devices. The submunitions are discussed in more detail later in this report. The length of time it has taken to develop and deploy viable anti-tank smart submunitions raises a major concern regarding the effectiveness of DoD's ability to bring advanced technology into application in a timely manner.

Smart Submunitions

Two major types of smart submunitions, terminally guided submunitions and sensor-fuzed submunitions, were being investigated in the Assault Breaker timeframe. These are both now being used in various submunitions. Both operate by searching out an area on the ground for targets (an armored vehicle) and accurately delivering a projectile to it. (The terminally guided submunitions fly directly into the target, sometimes described as "hit-to-kill"; the sensor-fuzed submunitions shoot an explosively formed penetrating rod into the target from a distance of 100 m or so, described as "shoot-to-kill."). Small size allows several submunitions to be packed in a single delivery device. Because they can search out areas 100 to several hundred meters across, they do not have to be precisely delivered by aircraft or surface-to-surface weapons. Since they are able to detect and precisely locate targets autonomously, they can achieve a greater number of kills per pass. In the late 70s and early 80s two sensor technologies were principally used in smart submunition designs: **infrared** detectors, which sense heat—typically coming from the tank's engine compartment; and **millimeter wave** detectors, which can either be passive—which sense a different wavelength of heat radiation than do infrared detectors, but with poorer resolution—or active, which is a form of radar, with better resolution than typical longer wave-length radars. How well these sensors can detect tanks under a variety of conditions, including the presence of countermeasures that the Soviets might deploy, was the focus of the joint Army-Air Force program.

The major issues determining the choice between a terminally guided submunition (TGSM) and a sensor-fuzed weapon in any given application were considered to be: (1) cost (sensor-fuzed weapons are cheaper by a factor of 5 to 10); (2) "footprint"—the area on the ground searched (TGSMS cover an area some 50 times greater); and (3) lethality (TGSMs, which use a shaped-charge explosive, have a greater penetration than the explosively formed penetrators).

Terminally guided submunitions (TGSM) were designed to be released from a missile, rocket, artillery shell, or aircraft and, after falling to an altitude of several hundred meters, would begin to glide at a steady altitude with their seekers scanning back and forth across a track on the ground, 500 to 1,000 m wide. The length of the search "footprint" depends on the speed and altitude at which the TGSMs are released; it might typically be several kilometers. When the seeker detects an object on the ground that matches the characteristics of a tank, it sends a signal to the guidance system to steer toward it by adjusting its control fins. A shaped-charge warhead, containing a few kilograms of explosive, detonates on impact.

[43] Ibid.

PROGRAM TESTING HISTORY

The phased approach to testing allowed individual technologies to be evaluated and then tested with other component combinations. In 1981 testimony provided the Senate Appropriations Committee, the DoD reported that:

> From 1978 through the first quarter of FY 1980, initial component technologies were developed and demonstrated for the Pave Mover radar, T-16 Patriot ground-launched missile and munitions dispersers, and terminally guided submissiles and submunitions. In FY 1979 and FY 1980, tests of the munitions dispensers, and terminally guided submissiles and submunitions. In FY 1979 and 1980, tests of the munitions dispensers at supersonic and high subsonic speeds proved the feasibility of stable, dispensing munitions in the flight regime of the free flight missile. In FY 1979 captive flight and tower tests demonstrated the capability of the submunitions to acquire, home, and impact on targets; in FY 1980 free-fall flight tests of the infrared terminally guided submissiles were conducted by two competing contractors. Those free-fall flight tests using millimeter wave radar seekers were not successful, and that effort was terminated in late FY 1980. A second smart bomblet submunition for use against soft targets was successfully tested in February 1980 and selected for flight demonstration. Roof House tests of the Pave Mover radar in FY 1979 proved that the goals could be met for target surveillance, target tracking, and weapon guidance. Development of two competing radars continued.[44]

The DoD went on to detail current activities and planned tests.

> The ground-launched version of the Assault Breaker weapon system concept is being demonstrated at White Sands Missile Range. The two competing Pave Mover radars have been integrated in F-111 aircraft and are undergoing surveillance and target tracking tests that will qualify Pave Mover for tests with the Assault Breaker missile. Both the infrared terminally guided submissiles and the smart bomblet submunition are completing full-function qualification tests at White Sands and Sandia Laboratories, New Mexico, to qualify them for the flight test program. The ground-launched Assault Breaker demonstration at White Sands is being conducted as a comparative evaluation of the T-16 Patriot and T-22 Lance II ground-launched missiles. Six missiles of each type are being fired in this phase of the program. The first two are being fired with inertial guidance to verify missile accuracy, demonstrate the capability of their dispensers to distribute dummy submunitions, and measure ballistic accuracy. The second two firings will evaluate the ability of the missiles to dispense live submunitions and the ability of the submunitions to achieve a "kill" on stationary tank targets.

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44 US Congress, Hearings before a Subcommittee of the Committee on Appropriations, United States Senate, Department of Defense Appropriations for Fiscal Year 1982, Part 4—Procurement/R.D.T.&E., Washington DC, US Government Printing Office, 1981, p. 43.

> The Pave Mover radar capability for tracking targets and the in-flight missile are also being evaluated. In the final two shots, the entire system will be evaluated against moving targets: the radar's ability to acquire and track a moving target and provide guidance to the missile; the missile's ability to guide accurately to the moving target and dispense its load of submunitions; and the submunitions' ability to achieve multiple "kills" in the target area.
>
> In order to demonstrate fully the weapon delivery options of the Assault Breaker concept, a joint test (DARPA and Air Force) of an air-launched version of the standoff missile will be conducted beginning in the first quarter of FY 1982. The test will consist of approximately six launches of the Assault Breaker missile from aircraft. Army T-16 missiles are being modified for air launch. The Pave Mover radar will provide target acquisition and guide the missile to target engagement by the seeker. Submunition dispensing and terminal effectiveness will also be demonstrated during the tests. The air-launched standoff missile flight test will be conducted from October 1981 through March 1982, in a parallel demonstration of the Pave Mover radar capability to guide penetrating manned aircraft for direct attack of targets.[45]

If the technology developed successfully, it would be transferred to the Services for further development and potential deployment.

> The air-launched phase of the Assault Breaker and the Pave Mover program will be transferred to the Air Force in late FY 1982 for further development of the Pave Mover system. Successful completion of the Assault Breaker technology demonstrations will provide a basis for decisions on engineering development for the corps support weapons system by the Army and for the Pave Mover radar by the Air Force in late FY 1982.[46]

The testing continued through FY 1982. Missile flight tests were conducted first with inertial guidance only and later with radar guidance, both ground and airborne used to steer the missile. Both the T-16 and the T-22 achieved desired accuracies. After these tests came additional tests that integrated the submunitions with the missiles and involved more complex command signals. The last testing phase, combining airborne radar with the missiles and the submunitions, was conducted against tank targets at White Sands. The final tests involved a ground-based radar simulating Pave Mover in late 1982. There were several failures, but in the last test, five General Dynamics TGSMs made direct hits, one on each tank in a pattern of five stationary tanks. Although the SKEETs did not achieve any hits in these final tests, it was generally agreed that the DARPA program had demonstrated the major technological features of

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45 Ibid., pp. 43–44.

46 Ibid., p. 44.

the Assault Breaker concept. With proof of concept established, a decision could have been made to enter full-scale engineering development if the Services had adopted Assault Breaker as a system.[47]

TRANSITION

A rapid transition from a proven concept to a coordinated Assault Breaker development program involving an integrated approach to long-range precision strike did not occur. While individual technologies were transferred to the Services from Assault Breaker and from the associated BETA and CELT programs, the transition effort was piecemeal and driven by individual Service decisions. An earlier study by the Institute for Defense Analyses stated that on the whole, the Assault Breaker "transition from proof of principal to operating system has a complicated history."[48] However, it was more than complicated—it never really occurred in the form envisioned. But the failure to pursue a rapid transition of this concept should not come as a surprise since it entailed a highly ambitious joint operational concept that directly brought together competing interests of two Services. Indeed, the high-level management structure that Dr. Fossum laid out in his testimony to Congress, aimed at facilitating such a transition, was an acknowledgement of the expected difficulty of the transition from concept to operation.

There were a number of obvious obstacles to an easy transition to the development and deployment of an operational long-range precision strike system at that time. First, a rapid transition would require fundamental changes in both Army and Air Force operational doctrine. It would, for example, necessitate closer cooperation between the Services and Army dependence on Air Force targeting. The flip side of that Army targeting dependence is that the change also required the Air Force to accept the Army targeting support mission rather than simply finding and attacking the deep targets by itself. Second, any transition would compete for scarce Service resources. A rapid and radical change in force structure (involving the introduction of more long-range missiles) would be particularly taxing. A rapid acceptance of long-range precision missile attack might call into question the need for more M1 tanks as well as for the F-16 aircraft that were being acquired. Third, it should be remembered that while the concept might have been shown to be technically feasible, it was still a long way from being operationally proven. The final "successful" tests conducted in 1982 had not actually involved all elements (for example, they had used ground-based radar to simulate the Pave Mover), and they had been carried out against stationary rather than moving targets. While such test results may have been

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47 Richard Van Atta et al., *DARPA Technical Accomplishments*, Vol. II, p. 5-11.

48 Ibid.

sufficient for demonstrating the technology to the S&T community, it would be less persuasive to Service personnel with near term operational responsibilities. Lastly, Assault Breaker and the two associated programs had developed in good part as a result of the assessment that on-going Service and DARPA technology efforts could be leveraged to achieve the long-range precision strike objectives stated by Dr. Perry in his 1978 testimony: “to be able to see all high value targets on the battlefield at any time; to be able to make a direct hit on any target we can see, and to be able to destroy any target we can hit.” Those Service programs still existed in some manner either as a part of Assault Breaker or in parallel to Assault Breaker. Pursuing the technological developments as Service Programs rather than as a joint program promised to provide many of the benefits touted for Assault Breaker with far more individual Service control of funding and technology direction. This was a tough set of obstacles for the Steering Group to overcome.

The transition process is discussed below in the context of Dr. Perry’s stated objectives.

See All High Value Targets

The Assault Breaker Program’s effort to demonstrate the ability to “see all high value targets” centered on development and testing of the Synthetic Aperture Radar (SAR) and Moving Target Indicator (MTI) R-MTI battlefield detection system. But the ability to see all high value targets involved not only those that could be located by the SAR and MTI flying aloft, but also the ability to target other high value targets that might be stationary but emitting communications signals (e.g., Command Centers) and to coordinate all this available targeting information into useful targeting plans and execution. Some of those fusion and collection capabilities were tested in CELT that helped locate and target enemy transmitters and BETA that tested the ability to be able to process all the information gathered by various sources and communicate them to forces for attack.

Pave Mover

The inter-Service aspects of the technology complicated the Pave Mover transition. To be sure, there was agreement between the Army Training and Doctrine Command (TRADOC) and the Air Force Tactical Air Command that the airborne targeting capability was essential to meeting the Soviet armor threat in Europe.[49] But there were contending priorities in each of the Services and several other on-going Army and Air Force target acquisition programs to consider.

49 Interviews with Generals Starry and Creech.

One of these was the Army's SOTAS program. After a review, SOTAS was canceled and Pave Mover was transformed into the Joint Surveillance and Target Acquisition Radar System (JSTARS) with the Air Force's Electronic Systems Division (ESD) as the lead service for the program. A 1983 DoD Memorandum included JSTARS as one of several joint programs designed to attack enemy forces deep behind the front lines.[50] Between 1982–1984, the Services, OSD, and Congress focused on developing the requirements for the joint program and identifying an appropriate aircraft. There was support in Congress for using a stealth aircraft derived from the TACIT BLUE test aircraft. However, the Services generally opposed this on the grounds that the sensors and operational requirements negated any stealth advantages and the stealth aircraft would have been extremely expensive. In May 1984, the Chiefs of Staff of the Air Force and Army signed a Memorandum of Agreement that rationalized the long-range precision strike efforts. Under the terms of the Memorandum the Army would build a ground launched ballistic missile system and the Air Force would build an air launched cruise missile under the Joint Tactical Missile System (JTACMS) Program. The Army and the Air Force would support and work together on a single JSTARS platform to be operated by the Air Force in such a way as to provide dedicated support for ground commander requirements.[51] A subsequent agreement designated a modified Boeing 707 (E-8A) aircraft as the JSTARS platform.

A Full Scale Development contract was awarded to Grumman Aerospace Company in September 1985. The first full test flight using the radar occurred in December of 1988. Also in 1988, the Defense Acquisition Board increased the number of E-8 aircraft to be built from 10 to 22 and, because of the high cost of refurbishment and conversion, approved a plan to use new Boeing 707 aircraft instead of the used commercial 707 airframes that had been originally been planned. By late 1989, however, because of changes in other programs, the cost of newly built E-8B airframes increased significantly. The Pentagon approved a change back to the used 707 airframes in the E-8C configuration. The initial operational capability (IOC) date was planned for 1997.[52]

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50 Richard Van Atta et al., *DARPA Technical Accomplishments,* Vol. II, p. 5-14.

51 Ibid.

52 "Joint Surveillance Target Attack Radar System (Joint STARS/JSTARS)", Federation of American Scientists. FAS Intelligence Resource Program Website, July 25, 1999, <http://www.fas.org/irp/program/collect/jstars>.

Although still under development, two E-8C aircraft deployed to Desert Storm in 1991. The aircraft flew 49 combat sorties accumulating more than 500 combat hours. The system was praised for tracking mobile Iraqi forces, including tanks and Scud missiles. Examples often cited in supporting its capability include:

(1) providing surveillance support of the battlefield during the battle for the town of Khafji where it detected a follow-on force of 80 Iraqi vehicles heading toward the town. This follow-on force was engaged and stopped by tactical airpower;

and

(2) surveillance of the Iraqi retreat from Kuwait City where it provided real-time information of the retreat to the air operations center supplying information that allowed commanders to use tactical airpower to interdict and destroy the Iraqi mechanized columns.

After the Gulf War, Congress sought to accelerate the procurement schedule, but the Air Force resisted because it felt that the use in the conflict did not alleviate the need for operational testing and further enhancements, but rather illuminated areas that needed more attention in development. In fact, the production configuration was not used in the Gulf War. Low-rate production of five E-8C aircraft was approved in 1993. This decision supported the developmental testing of the aircraft. Approval was also granted in 1993 for the low-rate production of 12 Mobile Ground Station Modules (MGSMs).

The JSTARS aircraft was scheduled to begin its initial operational test and evaluation in November 1995, but testing was changed because of the deployment of JSTARS assets to the European theater to support Operation Joint Endeavor in Bosnia. The Air Force Operational Test and Evaluation Center and the US Army Operational Test and Evaluation Command conducted a combined development and operational test from July through September 1995 and an operational evaluation of the system during Operation Joint Endeavor from January through March 1996.

From December 1995 to March 1996 a testbed E-8A and a production E-8C supported the NATO peacekeeping mission in Bosnia-Herzegovina. Operation Joint Endeavor proved JSTARS is effective despite adverse weather conditions and rough terrain. Crews flew 95 consecutive operational sorties and more than 1,000 flight hours with a 98 percent mission effectiveness rate. It returned to support Operation Joint Endeavor in October 1996 when the first production E-8C from the 93rd Air Control Wing and a testbed E-8C from Northrop Grumman Corp. deployed to Germany. As NATO rotated troops stationed in Bosnia-Herzegovina, crews flew 36 operational sorties in November and December for more than

470 flight hours. The second production aircraft joined the first after it was delivered to the Air Force in December.[53]

In September 1996, the Under Secretary of Defense for Acquisition and Technology signed an acquisition decision memorandum approving full-rate production with a total planned quantity of 19 aircraft. However, the JSTAR's performance during its combined development and operational test and the operational evaluation done in Bosnia was judged inadequate to support a decision to commit the system to full-rate production. A report by the Director of Operational Test and Evaluation stated that:

> In the current configuration, the [Joint STARS] aircraft has not demonstrated the ability to operate at the required maximum altitude; adequate tactics, techniques, or procedures to integrate [Joint STARS] into operational theaters have not been developed; [Joint STARS] exceeded the break rate and failed the mission reliability rate during [Operation Joint Endeavor]. During [Operation Joint Endeavor], [Joint STARS] did not achieve the effective time-on-station requirement.[54]

The DOT&E report noted that the limited power of the engines "made it difficult to reach the aircraft's normal operating altitude of 36,000 feet, much less the 42,000 feet maximum altitude it is required to reach." It further reported that during Operation Joint Endeavor, the aircraft required approximately 11,000 feet of runway when taking off with 140,000 pounds of fuel and concluded "this may pose a significant challenge to operational commanders because the NATO standard runway length is 8,000 feet."[55]

Despite such shortcomings, JSTARS provides a significant operational capability. It provides a common battle management and targeting capability to detect, locate, classify, and track moving and stationary targets for situation assessment to avoid surprise and to attack targets out to the range of existing and developing weapons. The joint Army/Air Force radar, airborne battle management workstations, airframe, data link, and ground stations provide the capability to locate, track, and classify tracked and wheeled vehicles beyond ground line-of-sight during the day and night and under most weather conditions. Radar data are distributed to the ground station modules (GSMs) via a secure surveillance and control data link. In addition to JSTARS radar data, the GSM is now capable of receiving and displaying Unmanned Aerial Vehicle (UAV) imagery as well as signals intelligence data via an integrated Commanders Tactical

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53 Ibid.

54 Ibid.

55 Ibid.

Terminal. It does not, however, currently have in-flight target update capability for updating the targeting for missiles.

BETA/CELT

Like JSTARS, the transition of technology from BETA was made more difficult by inter-Service differences. Its demonstration as an asset in the European theater appears to have facilitated its acceptance (at least in that theater). DARPA staff trying to establish a demonstration program, found that both the Army and Air Force had different requirements for sensor input and correlation and the Services were more intent on filling those requirements than on building a system that had sufficient sensor coverage to conduct an experiment. DARPA, as noted earlier, worried that "requirements creep" from the Services would overwhelm the experiment.[56]

Another obstacle was the existence of alternative Service systems. Faced with the alternative of testing two systems or proceeding with a single joint system, Dr. Perry decided that it would be best to pursue two systems rather than force the Services to agree on a single set of requirements. This resulted in ASARS (All Source Analysis System) for the Army and ENSCE (Enemy Situation Correlation Element) for the Air Force, which ultimately evolved into the Joint Tactical Fusion Program (JTFP).

BETA was successfully tested, but not in direct connection with Assault Breaker. Dr. Fossom, testifying before the House Armed Services Committee in 1981, reported "the BETA and CELT technologies were transferred to the Army and Air Force in FY 1981. BETA demonstrated the feasibility of a computer-based data fusion system that could operate in near real-time. Such data fusion was critical to exploitation of the air and ground-based sensors that were dedicated to finding enemy targets. The BETA technologies transferred were primarily the computer software capability to merge information from different databases into a coherent view of the battlefield. The CELT effort transferred the technology required to accurately locate narrow-band communication emitters based on a single intercept."[57]

BETA remained in Europe and evolved into the Limited Operational Capability Europe (LOCE) that for many years was the only automated fusion system in Europe. It was used in support of the Bosnia operation. Subsequently the Battlefield Information Collection and

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56 Robert Moore interview.

57 US Congress, Committee on the Armed Services, House of Representatives, Hearings on Military Posture and H.R. 2970, Part 4, Research and Development, Title II, p.165.

Exploitation System (BICES) was developed and implemented (starting about 1995). BETA served as an initial testbed for the concept of sensor data fusion, an element of which was fielded.

Hit All Targets We Can See

The Assault Breaker concept envisioned a ballistic missile fired from either the air or ground. The transition of missile technology in many ways had an even more difficult time than did the sensor technology. It faced many of the same obstacles, but these obstacles appear to have been magnified by the fact of the application of a technology (ballistic missiles) with few champions on the tactical battlefield. In contrast to the airborne sensor that met a largely unfilled need, the use of long range ballistic missiles threatened to crowd out some of the aircraft delivery systems for the deeper targets and reduce the need for tanks to meet a front line battlefield threat. This system called for major changes in operations and force structure: neither Service really liked the idea. One DARPA manager remembers a senior Army General telling him after receiving a briefing on the concept in 1978, that: "The Army doesn't like missiles and is anxious to retire the LANCE system."[58] While this view was not universal in Army management, and indeed there were on-going Army missile development programs, the view was sufficiently influential to have an impact on the nature of the Assault Breaker technology transition.

There were contending views in the Air Force as well. Most of the relevant Air Force weapons development community appears to have favored the development of a cruise missile rather than a ballistic missile. Because of the differing Service concepts of the missile's delivery system, neither Service was ever very supportive of a Joint Development Office. Both appear to have viewed the Office as an intrusive and overly restrictive management approach mandated by OSD.[59]

Tracking the transition of the technologies and concepts developed in the Assault Breaker Program into the individual Services weapons delivery systems reveals the difficulties of moving any technology into a military system. Successful transition requires champions, funding, and time. There were few champions for the missile delivery technology after it left the DARPA fold. Funding, as noted earlier, had to compete with other priorities, and the time to introduction was greatly extended. The basic concept of developing a seamless system from target acquisition

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58 Robert Moore interview.

59 See US Congress, Department of Defense Appropriations for 1985, Hearings Before a Subcommittee of the Committee on Appropriations, House of Representatives, 89th Congress, 2nd Session., LtGen Merryman testimony, p. 81. General Merryman asked by Congressman Dicks about the Program testified that the JTACMS was one of the things forced on the Services by OSD that did not make a lot of sense. He said the program was "overly restrictive and if we follow it, we would end up giving you something that won't work or would cost you more in the long run."

of mobile high value targets (tanks) to rapid target kill; one that had targeting flexibility in flight and kill capability against armor, was a long time in the development. Part of the reason for the delay might be explained because of the need to mature the technology. Another reason is the friction of the US political system, e.g., the change of Administrations almost always slows activities. A third reason was clearly bureaucratic resistance to change.

The Army Missile System Transition

The Assault Breaker Program was initiated and run at a time when some elements of the Army were interested in the development of a non-nuclear missile for use by Corps Commanders in Europe. The Army was working on the Multiple Launch Rocket System, as a means of meeting the massive Soviet artillery advantage, but the Service was also interested in a longer-range weapon to provide a conventional deep strike capability. While the nuclear-armed LANCE missile had a limited non-nuclear capability, the Army recognized the age and operational limitations of this weapon. It had terminated the LANCE Project Office and established the Corps Support Weapon System (CSWS) Project Office in the spring of 1980. A year later, prompted by Congressional and DoD concerns over Army and Air Force duplication in missile development, the CSWS Project Office was redesignated the System Development Office and given responsibility for management of the Assault Breaker Program, as well as the CSWS.[60] The following year the Under Secretary of Defense for Research and Engineering, James Wade, directed that the Army and Air Force pool the separate technologies developed under the Army's CSWS program and the Air Force's Conventional Standoff Weapon (CSW) program to form the Joint Tactical Missile System (JTACMS). Almost a year later, as a part of Dr. Wade's memorandum grouping various joint programs, the JTACMS Project Office was established to serve as the directing agency for a joint Army-Air Force program to develop a common missile system. The Army continued as the executive service.[61]

Firm-fixed-price contracts, funded on a 50/50 basis by the Army and Air Force, were awarded to Boeing Aerospace Company, Martin Marietta Aerospace, and the Vought Corporation to perform a capabilities and requirements evaluation of proposed JTACMS concepts. But, by the time these contracts were completed six months later, the Army's requirements had begun to specify that the system be an extended range MLRS, and the Air Force had independently issued a request for information (RFI) to industry. As these separate trends were developing, the Chiefs of Staff of the Army and the Air Force signed an agreement

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60 Army History of Missile Development, <http://www.redstone.army.mil/history/systems/ ARMYTACMS.html>.

61 Ibid., and Robert Moore interview.

stating that the Services would develop a joint statement of need for the JTACMS; that the restructured program would include the joint development of procedures to ensure that respective service components of JTACMS were fully complementary; that the Army would refocus its development efforts on a shorter range ground launched system; and that the Air Force would develop an air-launched system. Five months later in September 1984, the Air Force terminated its on-site participation in the JTACMS program.

The Army subsequently received approval from the DoD to develop an interim version of JTAMS to attack Warsaw Pact second echelon forces. By July 1985 the Army's MLRS and JTACMS Project Managers had signed a letter of understanding establishing the basic responsibilities and relationships in developing, producing, and fielding a composite battalion of MLRS and JTACMS. The decision to place the Army's version of the JTACMS in the MLRS battalion was probably critical to acceptance of the missile. The Vice Chiefs of Staff of the Army and Air Force subsequently issued a system description of the JTACMS to be developed, renamed the Army system Army TACMS, and clarified the relationship of the program. Very different missiles were being pursued by the two Services. The Army's ATACMS was approved for full-scale development in early 1986.

From here the ATACMS development appears to have followed a standard, and lengthy development process. An ATACMS Project Office was established in the spring of 1986. The Full Scale Development (FSD) contract for the Army TACMS missile/launch pod assembly (M/LPA) was awarded to the LTV Aerospace and Defense (LTVAD) Company at about the same time. Since the ATACMS would be fired from a modified M270 launcher, LTVAD, the MLRS prime contractor, was awarded a sole source contract for the launch/ ground support equipment and system integration. The first Army TACMS engineering development flight test was successfully fired at White Sands Missile Range (WSMR) in April 1988.

The Block I and Block IA missiles, were to be armed with an anti-personnel/anti-materiel (APAM) warhead, not the TGSM used in Assault Breaker. This was the warhead used earlier on the conventional Lance missile. The APAM could successfully attack soft targets including:

- Surface-to-surface missile sites
- Surface-to-air missile sites
- Logistics elements

However, in 1988, the Army directed that work begin on an infrared terminally guided submunition (IRTGSM) proof of principle program designed to further technology and to retain the IRTGSM as a viable candidate submunition for the ATACMS Block II program. Thus the objective of attacking tanks remained, but was pushed into the future.

Low rate initial production (LRIP) of the ATACMS BLOCK I, M39 Guided Missile and Launching Assembly began in January 1989. After additional design improvements, a 1-year LRIP of 66 Block I APAM missiles was authorized. An additional LRIP II contract for 104 M39s was awarded and finalized as a part of the Gulf War response in September 1990 and initial fielding of ATACMS was shifted from Germany to Saudi Arabia. Initially deployed with XVIII Airborne Corps in August 1990, the unit was later placed under operational control of VII Corps. Thirty-two Army TACMS missiles were fired against targets that included surface-to-air missile (SAM) sites, logistics sites, artillery and rocket battery positions, and tactical bridges. In the summer of 1991, the initial fielding of ATACMS to US Army, Europe and Korea was completed.

Development and upgrade continued and the Block II research, development, and testing program for FY 1992 included work to ensure that ATACMS could be the alternative Brilliant Anti-Armor (BAT) submunitions delivery vehicle. In October 1993, initial contracts for a BAT Preplanned Product Improvement (P3I) on the Block II were awarded.

R&D work between 1992 and 1995 included a possible Tactical Anti-Radiation Missile (TACARM), a Navy tactical missile (NATACMS), and Block IA extended range with an integrated global positioning system. In October 1993 initial contracts for a Preplanned Product Improvement (P3I) BAT submunitions on the Block II were awarded. This was followed by a decision to terminate the Army's participation in the Tri-Service Standoff Attack Missile (TSSAM) Program and to designate the ATACMS as the Army's primary BAT delivery capability. In 1994, the Army consolidated the Joint Precision Strike Demonstration (JPSD), the NATACMS Advanced Technology Demonstration (ATD), the Block IA (extended range ATACMS, and the BLOCK IIA (BAT) programs into a single management office.

In FY 2000, the Block IA was in full rate production. With enhanced Global Positioning System (GPS) accuracy, it has approximately twice the range of the original ATACMS Block I. Plans called for completion of the Block IA fielding in FY 2003. While the developments represented in ATACMS are vast improvements over the capabilities that existed before the Assault Breaker demonstration, the promise of combining the airborne sensing capability with precision deep missile strike against mobile tanks remains, twenty years after the successful demonstration, a future possibility. So too is the improved accuracy available through terminal guidance from the JSTARS. The Block II missile carrying 13 BAT submunitions entered low-rate production, but was cancelled in 2003.[62] The situation illustrates the difficulty of transitioning technology into operational weapons systems.

Air Force Tactical Missile

Although the Assault Breaker Program included a demonstration firing of a ballistic missile from an aircraft, the Air Force munitions development community was not supportive of the ballistic missile concept. The tactical Air Force was working on a number of delivery possibilities, but for longer-range missions it preferred to develop a cruise missile with loiter capability for a variety of interdiction missions.[63] In 1986, the Air Force began developing the Tri-Service Standoff Attack Missile (TSSAM) low observable conventional cruise missile and was the lead Service for the Program. TSSAM's characteristics included long-range, autonomous guidance, automatic target recognition, and precision accuracy with a warhead able to destroy a well-protected structure. The program aimed at developing a family of highly survivable, conventional, stealthy cruise missiles to satisfy tri-service requirements to effectively engage a variety of high value land and sea targets. All variants used a GPS-aided inertial navigation system. One Navy and Air Force variant used an imaging infrared terminal sensor for autonomous recognition and homing on fixed land targets and sea targets. Another Air Force-only variant contained the Combined Effects Bomblet submunition to attack land targets.

TSSAM however, suffered from both management and technical problems. After the TSSAM procurement unit cost increased from an estimated $728,000 in 1986 to $2,062,000 in 1994 (then-year dollars), the Department of Defense (DOD) terminated the program.

After a reassessment of force requirements, the Air Force and Navy agreed they still needed an affordable missile with many of TSSAM's characteristics and a new joint program was established in the fall of 1995, under Air Force leadership. The JASSM development schedule called for:

- A 24-month competitive program definition and risk reduction phase beginning in June 1996 (milestone I);
- A 32-month engineering and manufacturing development phase beginning in June 1998 (milestone II);
- Production of 75 low-rate initial production missiles beginning in January 2000;

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62 Lockheed Martin, <http://www.missilesandfirecontrol.com/our_news/factsheets/factsheet-ATACMS.pdf>.

63 Richard Van Atta et al., p. 5-16.

- Production of 90 full-rate production missiles beginning in April 2001 (milestone III); and
- Initial JASSM deployment in June 2001.

The program did not meet this schedule and was restructured in 1999. However, it began low-rate production in 2002.

JASSM's midcourse guidance is provided by a Global Positioning System (GPS)-aided inertial navigation system (INS) protected by a new high, anti-jam GPS null steering antenna system. In the terminal phase, JASSM uses an imaging infrared seeker and a general pattern match-autonomous target recognition system that provides aimpoint detection, tracking and strike.

Like the Army, the Air Force has developed a missile delivery capability that can perform many of the deep attack tasks envisioned in the Assault Breaker Program, but without the assistance of terminal guidance from JSTARS. Many critics continue to caution against too heavy reliance on GPS-guidance assistance.

Destroy All Targets We Hit

The final task of the long-range precision strike strategy, outlined by Dr. Perry, is to destroy the target. The Assault Breaker Program set the target kill criteria at the destruction of enemy armored vehicles—especially tanks. The Assault Breaker Program demonstrated two submunitions designed against tanks—the General Dynamics (GD) developed Terminally Guided Sub-Munitions (TGSM) and Avco's SKEET, a sensor-fuzed weapon that did not fly into its target, but rather descended in a fixed vertical or parabolic free-fall trajectory scanning for targets and fired a self-forging penetrator when the target was detected. The actual level of development of either of these submunitions at the time of the demonstration is somewhat difficult to judge. On the one hand there were reportedly successful tests. The GD TGSM, for example, had 5 hits with 5 devices in one test. However, it is not clear if this test or any of the other tests were set up to fully test all the actual operational aspects of the devices (for example, the submunitions were dropped from aircraft rather than fired from a missile). While the test may have been adequate for the air-launched JTACMS, it may not have been for the ground-launched missile. In any case, it is clear that some enabling technologies were more advanced than others. In testimony on the state of the technology, Army General Donald Keith, the Deputy

Chief of Staff for Research, Development, and Acquisition, addressed these issues. He reported that the Assault Breaker program was:

> …the first time we have tried to mechanize terminally guided submunitions. They are on a technology demonstration level. If that technology demonstration works, we will prove that the imaging infrared sensor works. But we will not have it micropackaged into the size that would be required for both the sensor and the warhead to occupy the volumetric space required for packaging these in a missile warhead. So we have another step to do technology wise.[64]

Queried by skeptical congressional staff that challenged the idea that much more work needed to be done to develop the submunitions, General Keith replied that there was still a need to do the "engineering" involved in turning the technology into a deployed product. This he noted is not an inconsequential task. While the technology existed, it had to be properly integrated and packaged.

> We will be leveraging off the technology base as it exists. There are a number of our contractors and our in-house laboratories that have been working this basic technology. We just haven't built one and demonstrated that we can loft it out of a missile warhead and make the individual submunitions scan, acquire and attack the targets.[65]

Ultimately the nature of the Services' submunitions used for long-range precision strike was influenced by many factors other than the results of the Assault Breaker demonstration. In the case of the Army, for example, it was influenced by the Army's development of the MLRS system. The ATACMS missile was sized to be fired from the MLRS launcher. This sizing had a positive effect on Army acceptance of the missile since it meant that there was no need for additional force structure changes[66] However, the sizing and the nature of the ATACMS development also affected the submunitions. The MLRS development involved international cooperative agreements and this ultimately influenced submunitions development. The US, Germany, France and the United Kingdom were all partners in the development of the MLRS. The DoD reported that the partnership was able to make use of some of the technology developed in Assault Breaker, but there were other trade-offs. The European partners reportedly preferred millimeter wave technology to IR. The US too expressed interest in other technologies such as

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64 US Congress, Committee on Armed Services, House of Representatives, 97th Congress, Hearings on Military Posture and HR 2970 for FY 1981. Part 4 of 6 Parts, Research and Development title II, p. 708.

65 Ibid., p. 709.

66 Interview with General Keith.

millimeter wave "because it has a greater capability to detect what is on the battlefield through obscurants, clouds and other things having a detrimental effect on IR."[67]

The submunitions initially deployed on the ATACMS as noted earlier, were anti-personnel and materiel (APAM) rounds. The ability to destroy tanks, the reason for the Assault Breaker Program, was expected to be a part of a later Block II upgrade. In fact, this is finally occurring in 2001. In order to keep the IRTGSM as a viable candidate submunition for the ATACMS Block II program, the Army decided to undertake an infrared terminally guided submunition (IRTGSM) proof of principle (POP) program. Contracts were awarded to General Dynamics Corporation and Raytheon Company in August 1989 for the POP Program and LTV Missiles and Electronics Group (LTVMEG), the ATACMS contractor, was subsequently awarded an Integration Contract to support the POP contractors. In June 1990, additional integration contracts were awarded to LTVMEG to study the integration of the millimeter-wave terminally guided submunition (MMW-TGSM) into ATACMS.

Brilliant Anti-Armor Submunitions

The Brilliant Anti-Armor submunition (BAT)—an unpowered, aerodynamically stable vehicle approximately 36 inches long in diameter, and weighing 44 pounds—was established in 1984 as a special access program and progressed to a successful engineering and manufacturing development phase decision in May 1991.[68] BAT uses a combination of acoustic and infrared sensors for terminal guidance: the acoustic sensor provides initial target detection and an infra-red sensor provides homing as it glides to the target to deliver a shaped charge warhead. This combined targeting and final guidance reportedly provides an advantage of an extremely large footprint, which allows it to compensate for target location errors. At the time it went into EMD, the expected carrier for BAT was the TSSAM. However, when the Army left the TSSAM program in 1993, the BAT program was restructured within the ATACMS program as an anti-armor variant for the missile. Changing the carrier from the TSSAM and technical problems reportedly delayed the Program for at least three years. Three components have taken the longest time to qualify and have contributed to the bulk of the schedule delay: the inertial measurement

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67 Richard DeLauer testimony, US Congress, House Committee on Armed Services, Department of Defense Authorization of Appropriations for FY 84 and Oversight of Previously Authorized Programs. Part 5: Research, Development, Test, and Evaluation, Hearing, March 1, 2, 9, 15, 17, 23, 24, April 12, 18–20, 22, 27, 28, 1983, pp. 231–267.

68 United States General Accounting Office, Report to the Chairman, Subcommittee on Military Research and Development, Committee on National Security, House of Representatives, BRILLIANT ANTIARMOR SUBMUNITION: Opportunity Exists to Conduct Critical Test Prior to Production Decision, GAO/NSIAD-98-16 October 1997, p. 2.

unit, the deceleration and stabilization system, and the infrared seeker.[69] These problems have been addressed over the last decade and BAT was delivered to the Army in limited numbers as part of ATACMs Block II starting in 2002. In 2003 ATACMs Block II and the BAT submunition P3I programs were cancelled. Beginning in 2002 a derivative of BAT, Viper Strike, has been employed experimentally as a munition on the Hunter UAV. Viper Strike uses a semiactive laser seeker to find its designated target.[70]

Army Sense and Destroy Armor (SADARM)

The Army was also developing the Sense and Destroy Armor (SADARM) prior to the initiation of Assault Breaker. The SADARM was designed to be a comparatively low-cost, fire-and-forget, sensor-fuzed submunition that could detect and destroy lightly armored vehicles, primarily self-propelled artillery. Once dispensed from its carrier, the submunition itself detects targets using dual-mode millimeter wave and infrared sensors and fires an explosively formed penetrator through the top of the target. Begun in 1978 by Aerojet Corporation, SADARM was to be delivered to the target area by 155 mm artillery projectiles or by the MLRS. However, the MLRS version was canceled in 1994 due to under funding. SADARM suffered a number of technical problems and program delays. One of the principal problems was reducing the size of the sensor package to fit into a 155 mm round and reducing the size of the penetrator, which made it somewhat less lethal.[71] After an extended development process, SADARM is now in low rate production and product testing and improvement.[72]

Air Force Submunitions

While the Army was working on TGSM, the Air Force's munitions community was pursuing what it termed a Wide Area Anti-armor Munitions (WAAM) Program. These munitions, designed to be dispensed by aircraft included: Anti-armor Cluster Munitions (ACM), an antitank missile known as WASP, and an Extended Range Anti-armor Mine (ERAM).

The Assault Breaker tested the Air Force Sensor-Fuzed Weapon (SFW)—termed Skeet by AVCO, its developer. These submunitions ultimately developed into the Air Force's BLU-108 submunitions. Each of these submunitions contains four projectiles, an orientation and

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69 Ibid.

70 "Viper Strike Munition Released From Hunter UAV Scores Direct Hits in US Army-Northrop Grumman Tests," Northrop Grumman Press Release, April 9, 2003, <http://www.capitolsource.net/press_releases/ngpress040903.html>.

71 US Congress, Office of Technology Assessment, *Technologies for NATO's Follow-On Forces Attack Concept,* July 1986, p. 32.

72 <http://www.aerojet.com/>.

stabilization system, a radar altimeter, and a rocket motor. Each projectile contains an explosively formed penetrator warhead and a two-color infrared sensor. Neither the munitions dispenser nor the submunitions are guided. However, the projectiles, as discussed earlier, are designed to scan a wide area with their infrared sensors searching for targets. If they identify a target they fire a self-forging projectile at it. If the projectile does not detect a target, it detonates after a fixed elapsed time, causing damage to material and personnel.[73]

The Extended-Range Anti-armor Mine (ERAM) was an Air Force developed prototype "smart" mine, employing the Skeet submunition, designed with the ability to control a wide area, to discriminate between tanks and lower value targets, and to attack the lightly armored areas of the tank. The ERAM consisted of nine Skeet submunitions in a tactical munitions dispenser. After final tests of a prototype, the Air Force decided not to proceed with full-scale development in fiscal year 1987 as originally planned. The estimated cost at the time was $75,000 per TMD-load.[74]

Like the Army, the Air Force took almost a decade and a half to field an anti-tank capability such as that demonstrated in the Assault Breaker Program. Although the SFW had not done well in the Assault Breaker testing program, it appears that there should have been fewer technological and engineering problems related to the Air Force's submunitions than with the Army's since there appear to be less need for miniaturization and, if the Air Force chose a cruise missile or glide bomb for delivery rather than a ballistic missile, less equipment stress. However, like the Army, the capability to attack mobile tanks at long range did not occur until after the demise of the Warsaw Pact threat.

The CBU-97/B Sensor-Fuzed Weapon, containing the Air Force's BLU-108 (Skeet) submunitions, is seen as going "a long way toward meeting the Air Force's goal to be able to find, fix, track, target, and engage any moving ground target anywhere on the surface of the Earth."[75] Moreover, the end of the Cold War threat did not negate the need for such munitions:

> Originally, the Air Force envisioned the SFW as a Cold War weapon system useful in a "Fulda Gap" scenario, whereby large numbers of heavy Warsaw Pact tanks would concentrate to try to punch through NATO defenses at specific choke points and then race through Western Europe to the Atlantic. The SFW was going

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73 Robert C. Aldridge, "Precision-guided Munitions and the Neutron Bomb," *Policy Analysis, No. 15*—August 26, 1982.

74 US Congress, Office of Technology Assessment, *Technologies for NATO's Follow-On Forces Attack Concept—Special Report,* OTA-ISC-312 (Washington, DC: US Government Printing Office, July 1986) pp. 33–34.

75 Robert Wall, "The Devastating Impact of Sensor-Fuzed Weapons," *Air Force Magazine*, Vol. 81, No. 3, March 1998.

to be one of the weapons that kept the choke points choked with the blazing, burned-out hulks of Soviet tanks.

The end of the Cold War not only removed the original wartime scenario but also opened up new ways of delivering such weapons. With the end of the Cold War, USAF's heavy, long-range bombers were withdrawn from their nuclear orientation and revamped as conventional delivery systems. Thus, the number of potential SFW carriers increased dramatically.

Initially, the Air Force judged the primary delivery means to be F-16, F-15, and A-10 fighter-attack aircraft. Now added to the mix are the B-52, B-1B, and even B-2 bombers. All will be able to carry the SFW in large numbers.

One of the ironies of this dramatic turn of events, Air Force officials remarked, is that the SFW, a quintessential Cold War weapon, may well end up having even greater significance in the Post-Cold War world.[76]

Thus, the developments in standoff precision strike have definite application in Post-Cold War environment. However, the transition of the technologies took so long that they had little influence on the Cold War.

ASSAULT BREAKER'S RELEVANCE TO THE RMA

Defining RMA

For this discussion RMA is defined as embodying those technologies and operational concepts that provide significant new military capabilities and a step order improvement in the ability to apply military force over what existed during the past half-century. The past military epoch was characterized by the development of increasingly more mobile and flexible maneuver forces with almost global reach. These forces either used the massed firepower of many individual weapons, or the threat of the use of a relatively few indiscriminate nuclear weapons, to apply (or threaten) killing force and achieve their military objectives (recognizing that achieving compliance without the actual use of force is a valid, and indeed preferred means of achieving military objectives). The RMA applies to the global ability of military forces to selectively threaten or attack high value targets while reducing damage to civilian populations and structures and reducing our own casualties. Dr. Perry's formulation of precision strike objectives—*See all high value targets on the battlefield at any time; make a direct hit on any target we can see; and destroy any target we can hit*—is very much in the mainstream of this definition of RMA.

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[76] Ibid.

Assault Breaker's Relevance

The Assault Breaker Program had a positive affect on several of the capabilities for conducting long-range precision strike—a critical element of RMA as defined above. The impact of the Program is evident in the US force structure and of the concept of Precision Force outlined in the most recent version of the DoD's S&T planning documents. The Precision Force Concept, illustrated in Figure IV-1 drawn from DoD S&T documents, shows great parallel with the earlier Assault Breaker concept.[77]

Current Forces

US military force structure includes the JSTARS, whose lineage is through Pave Mover. While not used precisely as envisioned by the Assault Breaker Program (e.g., not providing terminal guidance updates for attacking missiles), the system is an important and valuable tool in acquiring and tracking ground targets. The ATACMS, while less capable than desired in Assault Breaker (e.g., still lacking the ability to kill mobile tanks), is a key part of the DoD's ability to attack deep targets—including lightly armored vehicles. The Air Force's CBU-97B, while not having extended range without a penetrating aircraft as envisioned in the Assault Breaker air-launched JTACMS concept, does now have the submunitions (BLU-108/B) to defeat tanks. The JASSM may give the Air Force that capability without the need for a penetrating aircraft. These newly deployed (or deploying) submunitions all have linkages to the Assault Breaker developments in terminally guided submunitions (TGSM) and Sensor-Fuzed Weapons (SFW). Unfortunately, as noted earlier in this paper, the capability to achieve what Assault Breaker demonstrated almost a decade and a half ago remains limited. However, the DoD S&T planning indicates that achieving that capability still appears to be an objective.

Future Plans

Recent DoD S&T plans outline future war-fighting thinking and future technology planning to support that technology. Figure IV-1 from the *1997 Joint Warfighter S&T Plan* illustrates the concept. Figure IV-1 looks remarkably similar to the ones illustrating the Assault Breaker concept that were shown to Congress in the late 1970s. JSTARS, is an important part of the picture overlooking the battlefield. The ground-based Battlefield Control Element, an outgrowth of efforts to collect and fuse information on the battlefield demonstrated in BETA is represented. An improved ATACMS, whose lineage is through the Assault Breaker missile testing, and provides an important attack capability, is there. New anti-personnel and anti-

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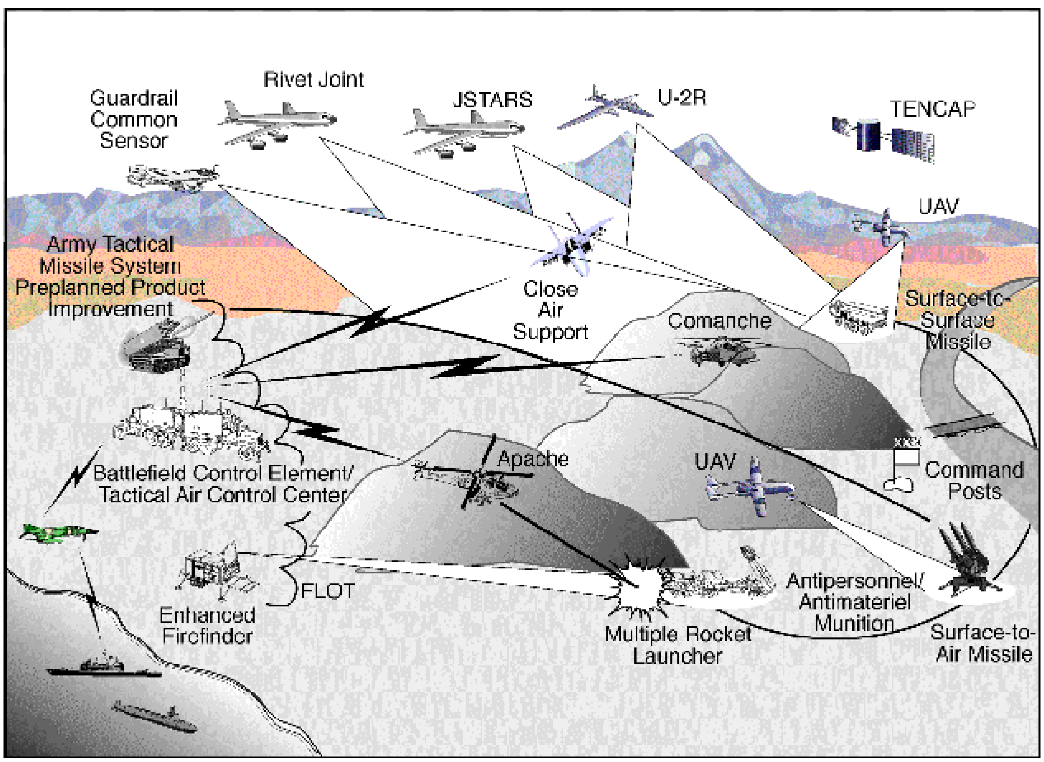
77 *1997 Joint Warfighter S&T Plan,* Chapter IV, "Achieving Joint Warfighting Capability Objectives", Part B. Precision Force, <http://www.fas.org/spp/military/docops/defense/97_jwstp/jwstp.htm>.

materiel munitions, whose development can be traced back through the TGSM, BAT, and Skeet, are represented. The concept also includes UAVs. While UAVs were not a part of the Assault Breaker program, for many years they were the focus of important DARPA research efforts (see Chapter VI) and are projected to play an increasingly important role in standoff precision strike. These systems, and their embedded technologies, all play important roles in the ability of future US forces to (1) see targets on the battlefield, (2) hit the targets that are identified, and (3) kill the targets that are hit.

In the S&T document, Precision Force is defined as:

> …the capability to destroy selected high-value and time-critical targets or to inflict damage with precision while limiting collateral damage. This capability supports mission requirements to rapidly neutralize hostile assets for communication, command and control, mobile or fixed weapons of mass destruction (WMD), attacking force projection elements and supporting infrastructure. Precision Force includes surveillance, targeting capabilities, and precision-guided munitions.[78]



Source: *1997 Joint Warfighter S&T Plan*, Chapter IV, "Achieving Joint Warfighting Capability Objectives", Part B. Precision Force, <http://www.fas.org/spp/military/docops/defense/97_jwstp/jwstp.htm>.

Figure IV-1. Precision Force Concept

78 Ibid.

Demonstrating that standoff precision strike is an area where ongoing technology developments are needed the document goes on to outline a range of technological needs related to Precision Force. These include: the timely combat decision and resource allocation processes in relation to target cycle time, the detection of highly mobile targets in crowded mission space, processes for fusing various service automated mission planning systems for target information, and means to overcome time consuming and incomplete battle damage information and assessments.

Improved capabilities for weapons employment include the ability to satisfy the simultaneous needs for sensor information; the improved ability of sensors to acquire and track multiple targets; better coordination of sensor information among battle managers; development of an all-weather/day-night precision (<3-meter CEP) weapon capability; improved efficiency for attacks against hard, buried, and strategic targets; ability to defeat GPS jamming; and more affordable precision-guided munitions.

Assault Breaker presaged the need for a complex of capabilities—system-of-systems—that could provide the ability for standoff precision strike. The program set the stage for initial experimentation with such integrated concepts that today are being envisioned in future defense plans. DARPA provided the impetus and the venue for developing these concepts and for the initial experiments to assess their value. While the nature of the threat has changed drastically, the concept of integrated standoff precision strike remains a major element of US defense strategy.

SUMMARY OBSERVATIONS AND CONCLUSIONS

1. There are clearly traceable technology developments tested in the Assault Breaker Program that are now a part of what we commonly term the technologies involved in the Revolution in Military Affairs. These include: JSTARS, ATACMS, and submunitions such as the BLU 108/B and BAT. While some of these technologies have evolved and acquired additional characteristics, the concepts and many enabling technologies are the same.
2. Possibly even more important than the testing and developing of specific technologies is the conceptual breakthrough in getting the Services to work together across the barriers of roles and missions to attack the Warsaw Pact tank threat. This cooperative approach was resisted by both of the Services, but facilitated by parts of the Army because they understood that the Service needed to work more closely with the Air Force to meet the European threat. Some leaders in the Air Force agreed with the Army on the need to change operational concepts and facilitated cooperation.

3. The exact nature of DARPA's role in the development of these deployed technologies is a matter of some dispute. However, it is clear that DARPA did play a role in facilitating the testing and development of technology and most importantly in proving out the operational concept needed to meet the tank threat. The development of the Assault Breaker Program was a very useful idea. DARPA also played a significant role in the enabling technologies (e.g., IR sensor development and others).

4. DARPA's main contribution might have been in testing the operational deep interdiction approach and in elevating the entire effort sufficiently to ensure that some funding would remain available to those elements of the Services that supported development and deployment. Even if this were DARPA's only contribution, it would have been critical.

5. The transition from proof of concept to deployed set of *integrated* technologies largely failed. The transition simply took too long. The *announced* threat largely disappeared before the technology was fielded. It was business as usual. The problem was partly technical and partly managerial, but in the end the scale and scope of the integration made the transition extremely difficult. Given the ambition of the concept there was a need to provide extraordinary management effort to adequately support transition. Even the efforts to support the effort through a Joint Program Office within OSD were not sufficient to bring the system into operation as an integrated capability.

6. Another part of the problem is Service related. The Services had other priorities. The Army continued developing and deploying tanks and helicopters and many in the Service did not want to invest in this new missile technology. So too the Air Force. The larger Service had more important acquisitions: the F-15 and F-16 for example. When competing with Service programs, even good new ideas will not get through the system without a powerful advocate—and for a Joint concept as sweeping as Assault Breaker the advocate had best be the Secretary of Defense.

7. The problems with the development and fielding of precision-guided submunitions needs to be given explicit attention. This is raised again in the next chapter in which the development of precision strike capabilities in the post-Cold War environment is discussed.

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V. DARPA ROLE IN THE DEVELOPMENT OF PRECISION WEAPONS IN THE POST-COLD WAR ERA

Jasper Lupo

EVOLVING NATIONAL DEFENSE IMPERATIVES

In the past 40 years, US national defense planning has gradually moved away from dependence on nuclear weapons, with occasional periods of heightened national focus on non-nuclear defense options. One such period is the decade from 1975 to 1985, when the Department of Defense (DoD) initiated a series of conventional weapons developments that, collectively, have fostered what today is termed a "Revolution in Military Affairs" (RMA). DARPA supported development of concepts and technologies that were key elements of this RMA. Today the technological opportunities that emerge from these developments—robotic systems, networked sensor arrays, embedded computing, machine vision, wireless communications, and precision navigation, among others—will likely continue to transform concepts of warfare.

National nuclear policy in the 1950s was known as the New Look. By relying heavily on nuclear weapons to conduct tactical warfare in Europe, the New Look allowed Eisenhower to reduce force structure to save money. But as Soviet nuclear capabilities increased, this strategy became increasingly unacceptable. Leaders in both the US and NATO found it politically unacceptable that nuclear weapons would be the only credible military response to increasing Soviet strength. The Europeans in particular could not embrace a defense strategy that contemplated Europe as a nuclear battleground. But it was not politically practical to increase NATO manpower and weaponry to match Soviet numbers.

The term "Flexible Response" was coined in the 1960s to describe a new strategy that called for credible, non-nuclear, military options in the European Theater. NATO Committee document 14/3 calling for Flexible Response was signed in December 1967. But there was little progress while the US focused on the war in Vietnam. Secretary of Defense James R. Schlesinger assumed office in 1973, convinced that the Army in Europe lacked credibility. With US attention turning back to NATO, he sought to make Flexible Response a reality. Subsequently, Secretaries Donald Rumsfeld (in his first term) and Harold Brown reaffirmed the Schlesinger policy.

US tactical forces at this time were viewed as being in disarray and providing inadequate capabilities to contend with the burgeoning Warsaw Pact forces. General Creighton Abrams, then Chief of Staff of the Army, referring to US losses and paralysis in Vietnam stated, "We are never going to let this happen to us again."[1] He was concerned that the North Vietnamese using Soviet artillery had outgunned US troops. Soviet-made artillery had greater range, and the US could not return fire because the enemy artillery could not be found. Furthermore, the 1973 Yom Kippur War stunned Army leadership. In just 18 days of fighting, the combined tank and artillery losses for both sides exceeded the total US Army inventory of tanks and artillery in Europe. It was clear that Soviet equipment and tactics had altered the balance of power in land warfare. Army leadership determined that a new kind of non-nuclear warfare with a new class of weapons was needed in order to stop the 80,000 tanks of a potential Warsaw Pact assault in the Central European Plain.

Abrams became a driving force for reform. He persuaded Schlesinger[2] to undertake a conventional weapons buildup, resulting in the Army Big Five:

- M-1 Abrams Tank
- M-2 Bradley
- Patriot air defense system
- Blackhawk Helicopter
- Apache Helicopter

Abrams recognized the profound impact that this modernization would have on Army doctrine. He also realized that there were serious deficiencies in NATO plans for conventional war against the Soviet Bloc in Central Europe. So in 1973 he created TRADOC—US Army Training and Doctrine Command—to explore new ways to fight and appointed General William DePuy as TRADOC's first commander.[3] General Donn A. Starry, the second commander of TRADOC, rewrote Army doctrine around the Big Five and emerging technologies of the 1970s and 1980s, many of them instigated by DARPA. In 1978, he introduced the AirLand Battle concept, which called for the Army to embrace deep attack and massed fires without the traditional front line. Under this concept the enemy could be in any direction, and attacks could create high intensity zones of lethal fire more than 200 kilometers away.

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1 Interview with Dr. Fred Wikner.

2 Wikner interview recalling conversation between himself and Dr. Schlesinger.

3 Colonel John F. Shortal, Army Chief of Staff Military Review, Headquarters, Department of the Army, Prepared by US Army Command and General Staff College, Volume LXXVIII, September–November 1998, No. 5, Professional Bulletin 100-98-9/10/11.

THE GENESIS OF THE DARPA RESPONSE

Schlesinger assigned the task of making Flexible Response a reality to Don R. Cotter, Assistant for Atomic Energy.[4] Cotter sought funds from DARPA and elsewhere to conduct a study on how to deal with the overwhelming Warsaw Pact force in Europe. The Defense Nuclear Agency provided the funds for the study, conducted 1974–1975.[5] Dr. Joseph Braddock of BDM led the effort using raw intelligence data provided by the intelligence community. The study was comprehensive and covered both conventional and nuclear aspects of Flexible Response.

The results of the BDM study were presented in a series of briefings to Mr. Robert Moore, then Director of the Tactical Technology Office at DARPA. One particular briefing in 1975 contained a highly classified description of Soviet concept of operations, elements of which had been seen in the Yom Kippur War. Dr. Fred Wikner outlined a five-element development as the conceptual US counter:

- Airborne radar to detect enemy movement from the air. The radar was to look deep into enemy territory, up to 300 kilometers.
- Ground surveillance radar to detect targets for the close battle out to 20 kilometers.
- Guided missiles for weapons delivery. This missile "bus" was to deliver multiple precision munitions to the target area. The bus was to be guided by inertial sensors with guidance updates from the airborne radar.
- Terminally guided submunitions. These were to be delivered by the guided missile bus. After release from the bus, the submunitions were to seek targets and automatically attack them.
- All source analysis for target development. This effort would combine inputs from the radars, intelligence sources, and message traffic to provide rapid targeting information.

Moore used these briefings and input from within DARPA and the contractor community to formulate the Integrated Targeting and Surveillance System (ITASS) program, subsequently renamed Assault Breaker, that embraced four of the five elements outlined by Wikner, omitting only the ground surveillance radar.[6] In a break from DARPA's traditional focus, Assault Breaker

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4 Cotter, originally from Sandia National Laboratory, had also served as Deputy Director of DARPA and had worked with James Schlesinger at the CIA and OSD.

5 DARPA was approached but declined to participate in a study focused on threats, policy, and doctrine rather than technology. This has traditionally been DARPA's stance. In this particular case, there appears to have been miscommunication about the nature of the study.

6 Interview with Robert Moore. See Chapter IV of this document for detailed discussion of Assault Breaker.

would be an integrated system of systems rather than just a collection of individual hardware developments.

DEFINING NEW CAPABILITIES

At the time of the BDM study and Assault Breaker, military ground operations were built primarily around the use of unguided iron bombs and artillery known as "dumb rounds." Unguided weapons are very inefficient: Less than one in 500 rounds hits anything important. This is true of machine guns, air dropped iron bombs, and artillery. By contrast, it was postulated that precision guided weapons could rival the effective lethal yield of nuclear weapons by applying explosive energy directly to the targets of interest.

In the early to mid 1970s, Dr. William Perry, the Under Secretary of Defense for Research and Engineering, identified precision weapons as key to the Offset Strategy,[7] a concept for realizing Flexible Response by synergistically leveraging several superior US technologies. Having fielded laser-guided bombs and artillery rounds, DoD knew that precision was effective. Perry charged the R&D establishment in 1975 with developing "smart" submunitions that, beyond just being precise, could search for targets in a complex battlefield and automatically attack upon finding a suitable target. Emerging sensor, processing, and guidance technologies needed to enable this were already being developed in DoD labs and in industry: imaging infrared seekers, passive millimeter wave sensors, signal processing algorithms, and radar.

Smart weapons could address a wide range of military problems. Table V-1 shows some of the qualitative features that distinguish the various targets. There is significant variability in the characteristics of each type of target. Similarly, from the weapons designer's perspective, there are numerous guidance options. The guidance spectrum in Table V-2 ranges from unguided all the way to loitering, autonomous weapons. An important feature of the targets and weapons spectrum is that *there is no single weapon and fire control philosophy to meet all requirements in a cost-effective way*. Many of the more interesting applications involve a mixture of these concepts. We consider these different concepts in turn.

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7 "What we put together then for the offset strategy was a combination. It was not just precision strike. Precision strike was at the heart of it, but it also involved stealth aircraft to deliver these precision weapons, and it involved an intelligence and reconnaissance system that would target for them. Those were the three components of what we called a 'reconnaissance strike force,' and the reconnaissance strike force was the heart of the offset strategy." William Perry, *Air Force Magazine*, April 1997, Vol. 80, No. 4.
For a description of the origins and content of the offset strategy, and its role in Desert Storm, see William J. Perry, "Desert Storm and Deterrence," *Foreign Affairs*, Vol. 70, No. 4 (Fall 1991).

Table V-1. The Targets and Their Properties

	FIXED		MOBILE	
	SOFT	HARD	SOFT	HARD
Target examples	*Logistics centers* *Rail Systems* *Choke points*	*Ammo storage* *Bunkers* *Tunnel Doors*	*Air Defense Sys* *TBM (Scud)* *SBM (SS-21)*	*Tanks* *Armored vehicles*
Warhead needed to kill	10–50 lb Area targets	1000 lb or more Precise vulnerable point	10 lb Small arms Low caliber	10 lb top attack Rod penetrator Precise aimpoint
Target location uncertainty	none	none	5 km	0.1 km
Terminal accuracy	5 m	< 1 m	5 m	< 1 m
Value, density & numbers	Target rich, high value	Few targets, high value	Sparse arrays, low numbers, critical	Target rich, high value in numbers
Hide properties & defenses	None to minimal Rely on range for defense	False vents, doors Brief vulnerability Concrete, rebar	Tree lines/canopy Light armor Nets, mobility	Thick armor Mobility Defilade, nets

Unguided Weapons

Until recently, the DoD's primary means of attack has been the unguided weapon or dumb round. Conventional artillery, tank guns, and air-delivered iron bombs constitute the bulk of the arsenal. To many, this is not a problem, especially in the low-intensity conflicts that have confronted us in Desert Storm and the Balkans, as unguided weapons are cheap, and the bullets, the bombs, and the means to deliver them are sunk costs. However, even in such conflicts the collateral damage of such weapons is a growing concern, and unguided weapons are ineffective in high-intensity conflict against large numbers of tanks and hopeless against critical mobile targets.

Command-Guided Weapons

Command-guided weapons home in on their target by obeying external commands after launch. This approach requires less "smartness" in the round than if the weapon were self-guided, making it less costly, and it also provides greater assurance that the weapon will only go where it is intended. Some examples of this kind of weapon are wire-guided bombs used by Germany in World War II, the laser-guided bombs used in Viet Nam and Desert Storm, fiber optically guided missiles, laser beamrider missiles, and GPS-guided bombs. A critical vulnerability and cost associated with command-guided weapons is the fire control system and platform. Generally, the platform must remain exposed and possibly radiating during the entire engagement, which may last up 20 or 30 seconds. GPS-guided rounds reduce this problem, but they have been limited to stationary targets, and the fire control system must geo-locate the target to high precision.[8] An additional issue with command guidance is the sustainable firing rate or throughput. Because the weapon must be guided, there can be a limit to the number of weapons that can be fired at the same time, an issue for high-intensity conflicts.

Self-guided and Smart Munitions

Self-guided, or "smart," weapons are designed to search for the target as it reaches the engagement area. The amount of area searched is an indicator of the smartness of the weapon. The DARPA Assault Breaker program mixed a command-guided missile delivery system with a load of smart projectiles. The projectiles were delivered to a known target area and designed to search up to a 100-meter diameter area to find their targets. Assault Breaker offered a very high firing rate with great precision at ranges that could reach deep into the enemy's second echelon with a kill rate against tanks equal to that of nuclear weapons, without the radiation and collateral damage.

Loitering Self-guided

Loitering self-guided weapons autonomously search up to several hundred square kilometers over a period of tens of minutes to several hours for high value, mobile targets. The loitering weapon may be a smart bus for carrying smart or dumb munitions (analogous to manned aircraft), or it may be a single munition with its own sensor and computer. (Unlike an Unmanned Aerial Vehicle, the loitering weapons would not be designed to return to its base.) In principle, loitering weapons offer an economical way to kill mobile, elusive targets, which have caused great concern for the past 20 years. In fact, no successful alternative has been found. Hence, the Services and DARPA continue to invest in this type of weapon, as will be detailed later in this chapter.

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8 The Affordable Moving Surface Target Engagement system, a DARPA program, is aiming to develop GPS-guided bombs for use against moving targets.

Table V-2. Guidance Concepts

	Unguided	Command guided, updated	Self-guided	Loitering Self-guided
Fire control philosophy	Aim, shoot, hope	Aim, shoot, guide, update, run	Fire & forget	Plan, launch, & manage
Required link to weapon	none	Wire, laser, RF, GPS, fiber optics	none	Telecomm optional
Most suitable target types	Area, high density, soft	Point, fixed, minimally defended, hard	Vehicles, tank columns, on roads in the open	Mobile missiles, air defense, fleeting
Moving target capability	Prefers stationary	Prefers stationary, moving stresses fire control	Good against convoys, tanks on the move	Deals with moving, hiding, fleeting targets
Firing rate	Very high	Low to medium fire control limits rate	High, multiple kills per delivery bus	Sporadic, target driven (like a mine), multiple kills per bus
Kill probability	< 0.2%	Up to 100%	50–100%	80–95%
Individual round cost	Very low	Low	Moderate (round)	Very high (loiter system)
Cost per kill	Very high	Moderate to high	Low to moderate	Only way to attack certain mobile targets
System cost driver	Supply chain for tonnage delivered	Fire control system	Seeker	Smart delivery system
Vulnerability	Very inaccurate	Fire control & platform, link to round, jamming	Decoys, terminal phase sensor defeat	Timeline, false alarm rate in search mode
Duration of mission	Time of flight from delivery system to target	Time of flight from delivery system to target	From a few seconds to a minute	tens of minutes to several hours
Area covered	Lethal area of warhead	Area covered by the standoff guidance system	Up to 10,000 square meters (0.01 square kilometer)	From 1 square kilometer up to thousands

DARPA PRECISION WEAPONS TECHNOLOGY PROGRAMS

The period from 1975 to 1990 was one of significant DARPA investment in technology and systems for deep attack and precision munitions. It marks an era in which the primary goal was the defeat of the Warsaw Pact in any conflict that would emerge during the Cold War. Smart and precision weapons for deep attack were considered to be a critical part of the arsenal. But the underlying investments in technology for smart weapons and precision strike can be traced even further back, as will be described in this section.

Automatic Target Recognition

Onboard computer and processing is an essential ingredient of any smart weapon. Advanced smart weapon systems typically rely heavily on automatic target recognition (ATR) software running in real time on high-speed processors. DARPA has consistently invested in ATR algorithms and processors for a variety of sensors, beginning in the 1970s with image understanding research. In 1983, the Director of DARPA approved a comprehensive ATR program for three sensor domains: passive thermal imaging, imaging laser radar, and millimeter wave range radar. This investment covered all aspects of ATR development, sensor phenomenology, and evaluation. The program emphasized metrics and standards to evaluate whether and to what degree ATR could provide a useful military capability in smart weapons and surveillance platforms. These programs produced standard data bases for the millimeter and infrared ATR communities to train and evaluate their algorithms. Many kinds of algorithms and processing schemes were supported to include template matching, neural networks, and model based vision concepts.

Infrared Focal Plane Arrays

Seeker designers have long considered medium and long wave infrared to be important spectral regions. Many of the advancements in infrared arrays came from DARPA support in the 1970s and 1980s. Although most submunitions have used small, scanning arrays to construct scene images, DARPA made a strong push for staring focal plane arrays (FPAs) for seekers in the late seventies and eighties.

In 1982, the author came to DARPA from the Army Night Vision Laboratory (NVL) to be the first Program Manager for uncooled FPA technology. (DARPA had previously provided NVL with joint funding for the development of short-range individual soldier night vision aids.) Started in 1983 and continuing today, the Uncooled FPA Program had as its primary goal the development of low cost, room temperature, staring imaging capability for advanced submunition seekers. The first program invested in two approaches: ferroelectrics and bolometers. The former relies on a steep temperature dependency of the dielectric constant; the latter, on the variation of resistance with temperature. It was recognized even at that time that the probable winner in the long run would be the bolometric approach since it relied simply on advancements in silicon lithography. The technology was further accelerated by substantial DARPA investments in micro-electromechanical systems (MEMS) in the 1990s; the MEMS thrust led to maturation of processes for 3-D microstructures vital to thermal isolation of the detector elements in the arrays. As a result of years of investments, uncooled FPAs today are achieving sensitivity of .05 Kelvin (1/200 degree C) in 50 microns or less. DARPA continues to fund further improvements. A result of this technology evolution, a micro Forward Looking Infrared (FLIR), is shown in Figure V-1.

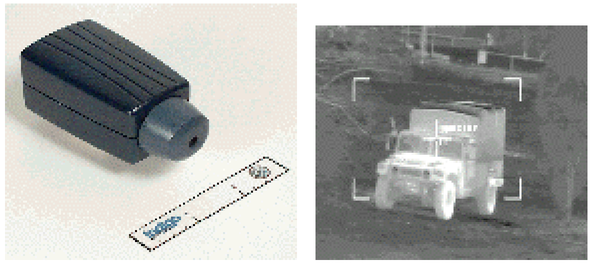

Figure V-1. The Army Center for Night Vision and Electro Optics (CNVEO) Micro FLIR Using DARPA Developed Uncooled Focal Plane Arrays

Millimeter Wave Radar

DARPA made substantial investments in Millimeter Wave Radar from 1975 to 1990. The technology was attractive to munitions seeker designers because it would theoretically provide enhanced performance over infrared seekers in poor weather, smoke, and dust. However, when compared with thermal imaging, these radars have large beam spread. A typical beam is on the order of 1 degree, over a hundred times coarser than the angular resolution of an infrared imaging sensor. But thanks to high-speed electronics, a high-resolution range profile of the target can be obtained in the transmit direction of the radar pulse. Thus, the signal representing the target is linear as in Figure V-2, not a 2-D image.

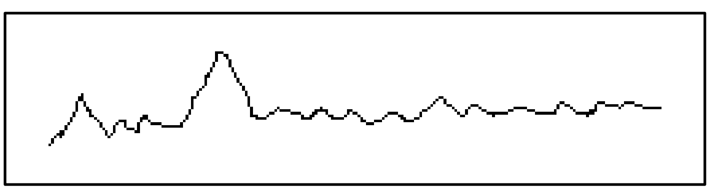

Figure V-2. A Typical Millimeter Wave Range Radar Signature, with Amplitude on the Vertical Axis and Range on the Horizontal

A problem with millimeter wave radar is that the target signature will vary dramatically with viewing aspect. Because of its inherently superior weather and dust penetration vice thermal imaging, much effort has gone into this technology in an attempt to compensate for its highly volatile target signatures. DARPA studied extensively the hardware, phenomenology, and software needed to provide high-performance ATR using millimeter wave range radar. It was found that algorithm performance was highly variable and that target signatures were volatile. Polarization improved signal to noise ratio, while Doppler beam sharpening tightened the effective beam and thus reduced clutter. Still, today ATR for high range resolution radar is limited to alerting or cueing for imaging systems. The Apache Longbow millimeter wave radar, fielded in the 1990s, is used to classify targets for the Hellfire missile, which reacquires the target using information provided by Longbow.

Imaging Laser Radar

DARPA investigated the value of Laser Radar (LADAR) for seekers because it adds several new modes of imaging and one spatial dimension. In theory, a seeker that can see in three dimensions should make fewer mistakes than one that can only see in one (millimeter wave) or two dimensions (passive thermal). In the early to mid-1980s, DARPA invested in the first multidimensional sensor program relying heavily on laser radar. The sensor had high-resolution micro and macro Doppler (meaning that it could both "listen" to target vibration and measure a moving target's velocity), reflectance range imaging modes, all with high spatial acuity. Massachusetts Institute of Technology's Lincoln Laboratory (MIT/LL), funded by DARPA, laid out the basic concepts for various LADAR imaging modes to include basic 3-D range imaging, template matching in 3-D, velocity imaging in both macro and micro Doppler modes, image transformation and rotation, 3-D ATR to include 3-D template matching and neural network processing, and range slicing to "peel away" foliage and camouflage.

Other developers in industry were using LADAR in various DARPA systems but were constrained by packaging and other practical limitations, whereas the MIT/LL work was free to investigate the basic phenomenology. This work also pioneered use of short wavelength lasers operating to achieve high spatial resolution of less than 30 centimeters in each dimension. The power of improved resolution was found to be more important than the penetration of adverse weather afforded by longer wavelength CO2 lasers. This paved the way for smaller, more reliable, solid-state laser radars of today. These concepts are receiving new interest because of new lasers and detection schemes that can shrink laser seekers dramatically while improving performance. The Air Force Low Cost Autonomous Attack System (LOCAAS) currently under development uses this technology to search for and recognize its targets (see Figure V-3). The use of a short wavelength laser, as initially done at MIT/LL in 1987, provides a small seeker that can fit in this loitering attack weapon designed to hunt and kill critical mobile targets. LOCAAS is about a meter long with a wingspan of one meter. As with the DARPA programs that preceded it, this development is aimed at attacking fleeting targets such as mobile missiles.

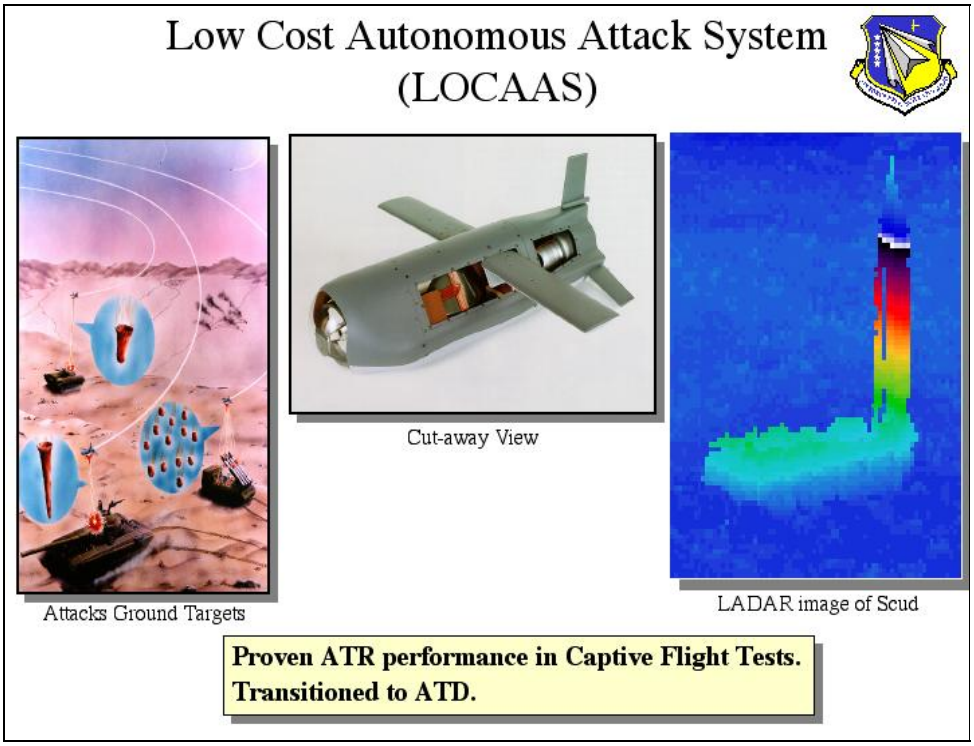

Figure V-3. The Air Force LOCAAS Program is Using 3-D Template Matching ATR Concepts Similar to Those Pioneered by DARPA LADAR Projects of the Mid-1980s

Computation and Electronics

Aladdin—"a gigaflop computer in a soup can"—was developed using funds from the Balanced Technology Initiative (BTI). Because of the rapid pace of computer technology, it was nearly obsolete on delivery; however, the testbed units provided a useful platform for ATR algorithm testing at the Army Center for Night Vision and Electro-Optics (CNVEO) for several years in the 1990s.

To help weapon systems navigate to hit targets, DARPA developed the first miniature Global Positioning System (GPS) receiver in 1988 and numerous approaches to miniature inertial navigation.[9] The miniature receiver weighed 8 ounces and fit in a handheld package the size of a cell phone. Miniature GPS receivers led to the fielding of JDAM, the first new precision guided bomb since the laser guided bombs of Vietnam.

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9 DARPA SPO Web site, <http://www.darpa.mil/spo/programs/ggp_mgr.htm>.

Key to this development was a set of gallium arsenide chips developed in the DARPA Monolithic Microwave Integrated Circuit (MMIC) program. These MMIC chips, coupled with silicon microprocessors developed in the Very High Speed Integrated Circuit Program (VHSIC), provided all the functions needed for this handheld device. A critical component of the chip set was a gallium arsenide MMIC device that contained the radio and intermediate frequency mixing and signal quantizer functions. Today, the entire GPS receiver fits in a wristwatch. MMIC devices have also enabled the RF and millimeter wave circuits needed in precision weapons that employ those frequencies for active and passive seekers. For example, SADARM (Sense and Destroy Armor) weapons use MMIC devices for the millimeter wave seeker functions.

DARPA PRECISION WEAPON INTEGRATIONS AND DEMONSTRATION

Assault Breaker

In December 1982, five self-guided projectiles were dropped out of the delivery missile system at White Sands Missile Test Range. All five of them succeeded in hitting one of the parked tank targets. This was one of the most integrated and complex DARPA demonstrations ever attempted. The munitions were fully functional weapons with seeker, computer, warhead, and software. Figure V-4 shows the Assault Breaker concept.

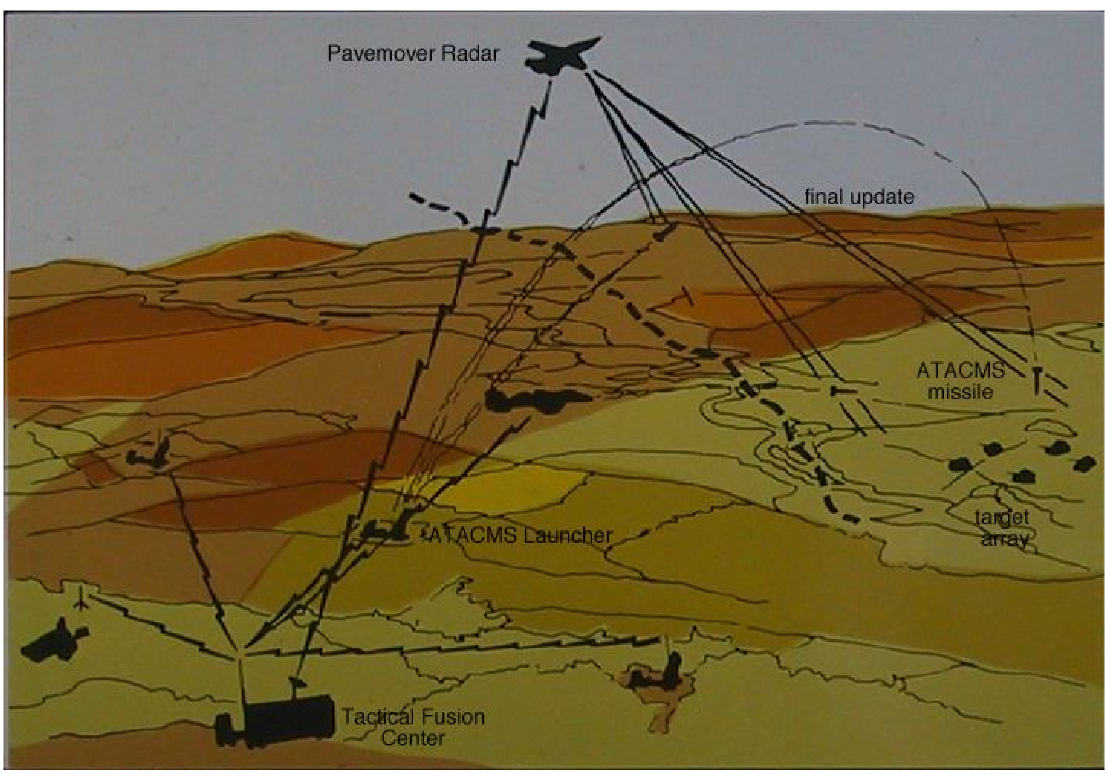

Figure V-4. The Assault Breaker Concept of Operations

The munitions were delivered to the target area by a missile that received guidance updates from the Pave Mover radar. At the delivery point, the radar told the missile to release the munitions. The terminally guided submunitions (TGSMs) then autonomously searched the local area for targets, selected one, and fired a penetrating rod into the target. The projectiles were launched from a long-range guided missile a few hundred meters above the target array. The submunition was 150 millimeters in diameter and about a meter long. It found the target with a two-color infrared imaging seeker. The dual wavelength response allowed it to reject simple countermeasures.

Each weapon had a 3–5 micron infrared imaging seeker that provided coarse day/night picture of the target zone with a resolution of about 1.5 meters at the release altitude of 800 meters. This permitted the software to tell the difference between a tank and a truck, but not what kind of tank. At this altitude, each munition scoured a 75-meter diameter circular area on the ground. The "picture" was processed by a small computer to look for bits of the image that were most "tank like." The sensor and software were designed to reject simple countermeasures such as fires and bales of hay. Before the submunitions had fallen 600 meters, they had to separate the tanks from the rocks, then pick an aim point on the target to within a meter, and trigger the firing of the weapon. The high-speed, explosively formed penetrating warhead then flew about 100 meters down to the top of the tank, where tanks are most vulnerable. This complex capability was packaged into a cylindrical package about a 1 meter long and 150 millimeters in diameter, weighing 30 kilograms.

The closest thing to the Assault Breaker TGSM submunition in the field today is the SADARM weapon, which entered the inventory in the late 1990s, after over 20 years of development in the Army R&D system. SADARM has many of the features that were demonstrated in Assault Breaker, but it is used only in 155 mm artillery. Although there are plans on the drawing board to dispense SADARM from the Army Tactical Missile System (ATACMS) Block II, deployment has been considered eminent for at least a decade. SADARM entered low rate initial production in the late nineties and continues to be tested at Fort Sill and elsewhere. The weapon entered "first unit equipped" status in 2000.[10]

The almost 20-year gap between the demonstration of smart submunitions in Assault Breaker and their fielding is due to several factors. First, although the DARPA Assault Breaker

10 Also in service today is the Brilliant Anti-armor Technology (BAT) submunition, a precision engagement weapon that takes advantage of the US ability to develop a missile that integrates stand-off delivery accuracy with a submunition that has the required effectiveness to kill moving armor columns in the deep battle zone. BAT entered low rate production in FY 98, but it has just recently become operational, though only against moving columns of tanks. See Chapter III of this document for more detail on the development of BAT.

submunition design paid attention to countermeasures, skeptics felt the field tests did not go far enough. Secondly, while Assault Breaker was being developed in DARPA, the Army had competing smart munitions programs under way: SADARM and BAT. Neither received any significant funding from DARPA during their developments. SADARM was on the drawing board before 1975. The Army was funding BAT in 1980. Thus, when Assault Breaker created yet another submunition, the Army simply proceeded to continue its own programs, even though neither does today what Assault Breaker demonstrated in 1982. Finally, the transition process was extremely complex, requiring the resolution of differences on many fronts. The former director of Assault Breaker believes that the submunition was neglected in order to maximize the transition potential for other portions of Assault Breaker.[11]

Tankbreaker

Although the DARPA Tankbreaker program did not develop a submunition, it was a driving factor for much of the technology that is relevant to the design of advanced submunitions. Tankbreaker (shown in Figure V-5) was conceived to replace the tank-killing Dragon, a shoulder-launched, wire-guided missile that required the gunner to remain exposed until the missile hit the target. The few seconds of guidance time were considered potentially fatal in the Warsaw Pact scenario. Therefore, Tankbreaker had to be a "fire and forget" missile; i.e., the soldier would launch the missile and dive for cover. Tankbreaker would also be a top attack weapon in order address the fact that Soviet tanks had improved their armor to the point where they rendered the frontal attack of Dragon ineffective. Finally, Tankbreaker would have to shoot further while weighing less than Dragon.

Figure V-5. An Early Mockup of the Shoulder Fired Tankbreaker and the Key to Its Fire and Forget Capability—the Staring Thermal Imaging Seeker (Right)

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[11] Interview with Dr. James Tegnelia, November 2001.

In order to achieve top attack capability in a shoulder-launched weapon, Tankbreaker would use a passive, imaging seeker with adaptive tracking algorithms that used routines found in basic ATR software. The staring infrared imaging seeker operated in the long wavelength region of the infrared spectrum (LWIR) in order to provide maximum smoke, dust, and weather performance, both day and night. The key to its compact design was the staring infrared focal plane array of 64X64 pixels. (At the time, such arrays were experimental.) The seeker had to be compact because it was gimbaled and had to fit into a 4-inch diameter. In order to achieve fire-and-forget operation, the seeker and tracking software had to lock on before launch and remain locked on during the entire flight of the missile. This presented problems for the software, which had to adapt in real time to scale aspect changes of the target. This was complicated by the fact that the missile would fly a curved trajectory for top attack rather than a flat trajectory along the ground. In addition, the software had to be able to reacquire the target after a brief period of "break track." In this regard, the tracking software can be regarded as a modest automatic target recognition capability.

The imaging focal technology was supported consistently by DARPA, with investments in several different approaches to maximize the chance that one contractor would achieve a producible design with adequate yield. In spite of this investment, focal plane yield caused problems early in the Army transition program. Fortunately, an alternate design was available thanks to DARPA's diversified development strategy.

Unlike the case of the Assault Breaker submunition, Tankbreaker made a clear transition from DARPA through the Conventional Initiatives Office to the Army Javelin program, in spite of competing technology supported by Army technologists. Fiber-guided and beamrider approaches had strong support at MICOM and in industry. The success is even more interesting since the first phase of the transition program re-competed the entire system without restricting technological approaches. Today Javelin is in the field. It entered full rate production in 1994, with over 9,000 units produced so far.[12]

Timing appears to be part of the reason that Tankbreaker transitioned while the Assault Breaker submunition did not. Tankbreaker technology was ready for competition at the right moment. The Army was ready to buy Javelin shortly after the Tankbreaker program reached its successful conclusion. In fact, the Army had been attempting to replace Dragon for over 10 years and had experienced numerous false starts and budget delays. The requirement for a new anti-tank missile was overdue. This kind of opportunity was never available for the Assault Breaker

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12 "Javelin Anti-Armour Missile," <http://www.army-technology.com/projects/javelin/>.

submunition. Probably another major reason is that the Army understood Dragon and how to use it. Unlike Assault Breaker, it did not require revised doctrine, nor did it require a new proponent, not to mention joint operations.

Autonomous Terminal Homing (ATH)

The ATH program was DARPA's response to a National Security Memorandum of the mid-1970s calling for improved non-nuclear capability against fixed high-value targets (HVTs). HVTs, such as aircraft hangars and revetments, are typically hardened and deep in enemy territory. The existing solution, the Tomahawk cruise missile, had two problems in trying to attack these targets: (1) getting lost on the way to the target and, (2) inadequate terminal accuracy to ensure that its warhead would kill the target. Studies had shown that a 10-meter miss distance with a 1,000-pound warhead would render the Tomahawk ineffective against HVTs.

The ATH program (illustrated in Figure V-6) set out to solve these problems and provide 1-meter terminal accuracy. With respect to the first problem, getting lost, two techniques are used to improve the reliability of Tomahawk flight path updating: terrain contour matching (TERCOM) and digital scene matching area correlater (DSMAC). These systems were designed to update the missile's inertial navigation unit (INU) by recognizing predefined waypoints (rivers and major highways). TERCOM uses a radar altimeter to measure terrain altitude variations along the line of flight. This linear height profile is compared with templates stored in memory. DSMAC uses a television camera to gather area images to compare with templates in memory. This area correlation was necessary to complement TERCOM for possible drift away from the line of flight. The software looked for terrain variations associated with the waypoints and tried to distinguish the desired waypoints from scene contrast variations, shadows, and changes. However, false or extraneous features easily spoofed the software, a problem exacerbated by the fact that the DSMAC camera had a very narrow field of view—a soda straw. A false or inaccurate scene correlation resulted in a false update to the INU and put the missile off course. The longer the flight, the more severe the problem became.

With respect to the second problem, the Tomahawk did not have a terminal seeker. It hit its targets blind. This meant that the burden of terminal accuracy rested squarely on the TERCOM, DSMAC, and the INU. Although the combination could provide miss distances as small as 10 meters, this is not adequate for the harder HVTs.

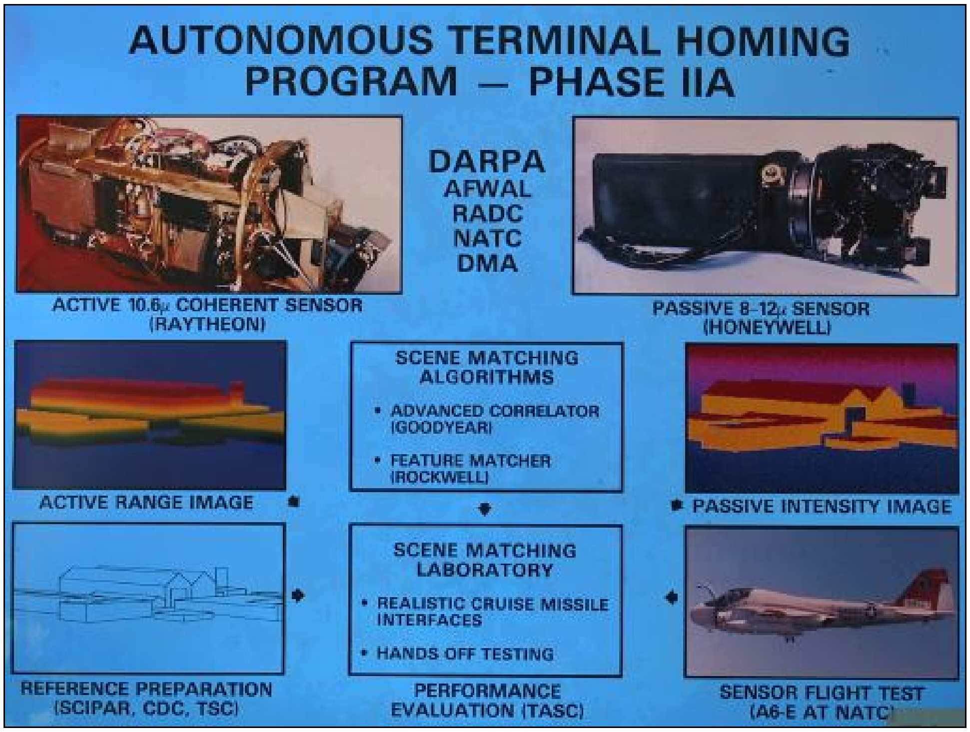

Figure V-6. The ATH Program Tested Two Approaches: All Weather, Day/Night Precision Navigation and Terminal Homing

ATH attacked both of these problems by testing day/night imaging sensors for two guidance functions: (1) scene matching with wide fields of view for terrain matching and following and (2) target looking modes for recognizing the target and aim point in the last kilometer of flight. Analyses of target vulnerability indicated that a terminal accuracy of 1 meter would be required for the Tomahawk warhead to be effective against HVT.

In 1983–84, two competing sensor pods were built and flown in over 120 flights in various, day, night, and weather conditions. The terminal accuracy goal was successfully demonstrated. An imaging laser radar was built by Raytheon in Waltham, MA; a passive 8–12 micron thermal imaging system was built by Honeywell in Lexington, MA. The Analytic Sciences Corporation, Lexington, MA tested various algorithm approaches on the data collected in the flight program. Both sensors collected imagery for terrain matching and terminal homing. Both designs required stored templates of waypoints for scene matching software to update the inertial navigation system, and a target template in the terminal phase to choose a precise aim point on the target. The scene and target matching algorithms were template matching, the standard technique of today's fielded ATR software.

Although the primary design called for ATH to look at the target during the last kilometer of flight, an offset guidance concept was also examined. In this case, the missile would correlate its sensed imagery with some unique scene feature near the target and use offset aiming to strike the desired aim point. The vulnerabilities and aim points had to be determined prior to flight time.

The program succeeded in demonstrating its guidance goals although the development of the flight path (waypoints) and target templates was considered to be too long (2 weeks for a new target). This lead-time necessitated the generation of templates ahead of time so that they could be downloaded into the missile prior to flight. This was a point of concern at the time because it could hinder timely operations against newly discovered targets in areas where prepared templates were unavailable. This is less of a concern with today's navigation and guidance technology.

The transition of ATH to the Navy did not occur, primarily because the maturity of the DARPA program efforts did not match the Navy's expectations. Hence, the Navy offered to serve as the transition proponent if DARPA would fund another phase of maturation and testing. This was unacceptable to DARPA management who felt that 120 sorties was enough to prove the principle. The Air Force therefore followed up on the transition with the Cruise Missile Advanced Guidance Program (CMAG). This was a modest transition in which the AF opened up the competitive field to all comers instead of pushing ahead with the DARPA contractors, who did well nevertheless. CMAG continued for several years and came close to entering full-scale development.

The advent of GPS reduced the importance of the ATH and CMAG programs, although some aspects of the technology may be applied in the future to deal with vulnerabilities of GPS (local jamming). For example, the ATH concept of offset aiming would allow a cruise missile to fly blind in the terminal phases of the flight, and thus would be immune to jamming. Meanwhile, the Navy continues to upgrade the guidance system with GPS entering service in 1993. Eventually, an infrared imager may provide man-in-the-loop control for the terminal homing phase. There seem to be no plans for an autonomous target-looking mode at this time, which may ultimately be the true legacy of ATH. However, the system may eventually carry SADARM and or BAT to provide a smart terminal attack capability.

SMART WEAPONS FOR FINDING CRITICAL MOBILE TARGETS: 1985–1995

Starting about 1985, DARPA efforts in precision weapons shifted away from tanks and fixed high-value targets to sparse arrays of hidden targets, particularly tactical and strategic mobile missiles such as the Scud.

The Smart Weapons Program

In 1983–1984, the Killer Robots concept was developed in the Tactical Technology Office (TTO) at DARPA. This proposed family of autonomous fighting vehicles never actually became a program, but it stimulated a lot of thought about the potential for unmanned combat vehicles. The motto of Killer Robots was, "The battlefield is no place for human beings." It included the following specific ideas:

- **Mantis.** This was to be a loitering air vehicle for Army/Marines applications. It was intended to loiter and attack using its magazine of onboard weapons, and could land to conserve fuel. Dormant time on the ground could be on the order of days.
- **Wolfpack.** This unmanned ground attack vehicle was to be the unmanned equivalent of the tank. It would have been deliverable by Army helicopter.
- **Sharkpack.** This unmanned Navy escort weapon platform would have provided defense for the fleet or supply convoys.
- **Hawkpack.** This was to be an unmanned fighter for attack of enemy bombers at extended range. It would have had extreme agility thanks to lack of pilot. The NASA HIMAT test vehicle was to be used to install the autonomous fighting payload consisting of sensors and computer.

In the same timeframe as Killer Robots, DARPA created the Strategic Computing Initiative (SCI), a major program designed to fund all facets of computing from parallel computer technology development to systems applications of high-end computing. A call for systems concepts went out to the DARPA PMs. TTO responded with the Smart Weapons Program (SWP), a mix of ATH, Killer Robots, and Assault Breaker ideas. Initially, SWP was supposed to expand and build on Assault Breaker by developing a modular family of smart weapons that would address the full range of national defense needs to include massed armor on the Central European Plain.

However, DARPA had just finished Assault Breaker, and the management believed that deep strike for the tank had been adequately addressed. Leadership in OSD and DARPA realized that the mobile missile was the next logical target of national interest. Intelligence data and analyses of the time revealed that the Warsaw Pact was fielding short- and long-range mobile missiles on a large scale. Training exercises and operations had been studied, revealing their concept of operations, storage areas, hiding strategies, and "shoot and scoot" tactics. It also revealed that they hide most of the time using camouflage, concealment, and deception (CC&D). This was a very tough problem suitable for SCI funding. It would stretch the limits of high-end computing with a heavy demand for real-time image processing, automatic target recognition, spatial reasoning, image understanding, and en route mission planning. Thus, a technology push effort from the computing community created the opportunity to attack this emerging national priority.

The SWP was approved in 1985 to pursue a true loitering autonomous weapon. The concept had been discussed since the mid-1970s, but the scale of the problem had prevented any Service from effectively pursuing such a complex and expensive program. By 1985, it was judged that emerging computer and software technology (including ATR) would enable such a weapon to be developed. Figure V-7 depicts the SWP concept.

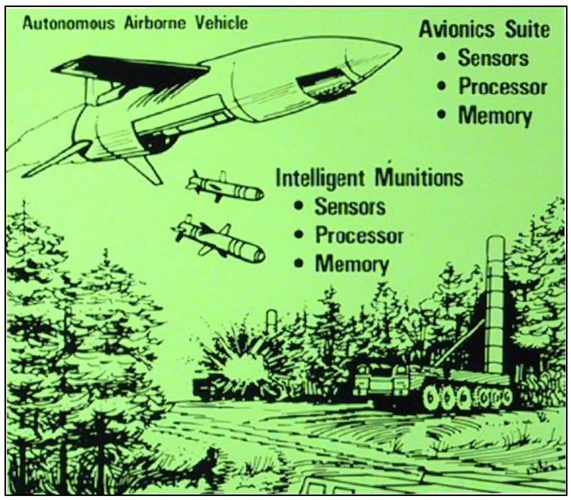

Figure V-7. The DARPA Smart Weapons Program of 1985 Drew from Assault Breaker and ATH to Address Widely Dispersed Mobile Missile

SWP inverted the roles of smartness found in Assault Breaker. Assault Breaker used a command-guided, dumb missile to carry smart submunitions to the target area. SWP would put almost all the brains in the missile bus, the Autonomous Air Vehicle (AAV), and make the submunitions as dumb (hence cheap) as possible. This was done to satisfy criticism that the system would be unaffordable and to minimize the risk that the submunition might fail to reacquire the target. In many ways, the SWP missile would be more like the ATH than the Assault Breaker missile. It would carry a high-end sensor payload that would begin where ATH left off; and the missile would fly search patterns in suspected target areas using complex automatic target recognition software. If a target were found, the onboard mission planning software would decide to dispense a munition to engage and then proceed to conduct more searches. Depending on the method of delivery, the submunition would navigate to the target using a low-grade inertial system or a modest terminal homing sensor that could reacquire using imagery fed to it by the bus. Use of very smart autonomous submunitions was left as an option but not part of the core program. At the end of the mission, any unexpended munitions (including the AAV) could be used in a kamikaze attack on a default fixed target of importance.

Unlike an Unmanned Aerial Vehicle, the loitering weapon would not be designed to return to its base. Some designers proposed recovering the AAV by having it fly back to a safe collection point. This idea evoked fears of fratricide and never caught on. Even Senator Sam Nunn humorously questioned the desirability of having such a killing machine come back home.[13] The missile would have carried 10 to 20 submunitions, thus giving it a substantial multi-target kill capability. This would lower the cost per kill.

The SWP hunter-killer idea inspired many, but it galvanized the proponents of command-guided and dumb weapons. Loitering weapons stretched military doctrine so far that no requirements organ in any Service felt that it owned the mission or idea. This would portend a difficult transition even if the technical efforts succeeded.

The technologists were delighted. The SWP hunter-killer concept challenged and expanded development of every smart weapons technology:

- **Automatic Target Recognition.** Up until that time ATR had been working with minimally resolved targets at the limit of sensor range. This gave the ATR few pixels on target (100 max), which limited ATR function to crude decisions and poor discrimination capability. A pixel on target was about 1 to 3 meters, depending on range. The SWP proposed to change that by an order of magnitude. The smart missile would fly close and put 1-foot pixels on target, thus allowing the ATR to recognize and even identify the type of mobile target it was looking at. Instead of saying this is either a missile launcher or a large truck, the ATR would be able to say this is a Scud, not a supply truck. This level of performance would be critical to ensuring a reasonable cost per kill of higher valued targets.
- **Automatic Smart Route Planning.** The AAV would be expected to execute its plans within overall guidance provided at launch time (with possible updates during the mission). It would adapt and revise its detailed search strategy and local plans on the fly based on sensor inputs, fuel, weapons load, and a host of other parameters. This software was being developed in other SCI programs and would be adapted to the AAV.
- **Smart Search.** Autonomous search strategies were merged with advanced pre-flight and in-flight route planning algorithms. AAV would fly low, search a likely target area, and then move to the next area.

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[13] Briefing to Senator Nunn, 1990.

- **Multi-sensor ATR and fusion.** Designers looked for combinations of sensors that included LADAR, passive thermal imaging, active and passive millimeter wave imaging, electronic sensing for emitter location, high range resolution radar, doppler imaging and mapping, synthetic aperture radar, and more.
- **Automatic Sensor Management.** All the competing AAV designs used muti-mode and multi-sensor suites. The onboard software was designed to manage the search modes and the high resolution, recognition modes, and feed sensor management needs to the higher-level route planner. It needed to manage handoff between search and attack modes, between different types of sensors, and decide when to use the various modes.

In 1985, seven industrial teams were awarded design study contracts for the first phase of the program. They were competing for the second phase, Thirsty Saber, which was to have two winners.

Thirsty Saber

Thirsty Saber, the second phase of the SWP, sought to define a transition path for the SWP payload. Because of its endurance and low observability, the Advanced Cruise Missile (ACM) was picked as the probable first transition for the sensor, brain, and munitions suite.

To avoid the cost of actually integrating the payload into the ACM, the program made extensive use of surrogate platforms for the major proof-of-principle demos. Programmatically and technically, TS was more like the ATH program than Assault Breaker. The winners of the first phase of SWP consisted of two teams: Martin Marietta, Orlando; and Texas Instruments, Dallas, with their subcontractors and partners. The Martin Marietta sensor suite consisted of a millimeter wave radar for search coupled with a passive infrared imager to perform model-based ATR. (An aggressive part of SWP was the ATR. Martin Marietta invented a concept called Key Features in which the ATR attempted to recognize the target by its structure. This concept is currently being explored as the next generation of ATR for the coming decade.) Texas Instruments used a passive thermal imager to search and an imaging CO_2 laser radar to provide images to the 3-D template matching ATR suite. The Thirsty Saber program is depicted in Figure V-8.

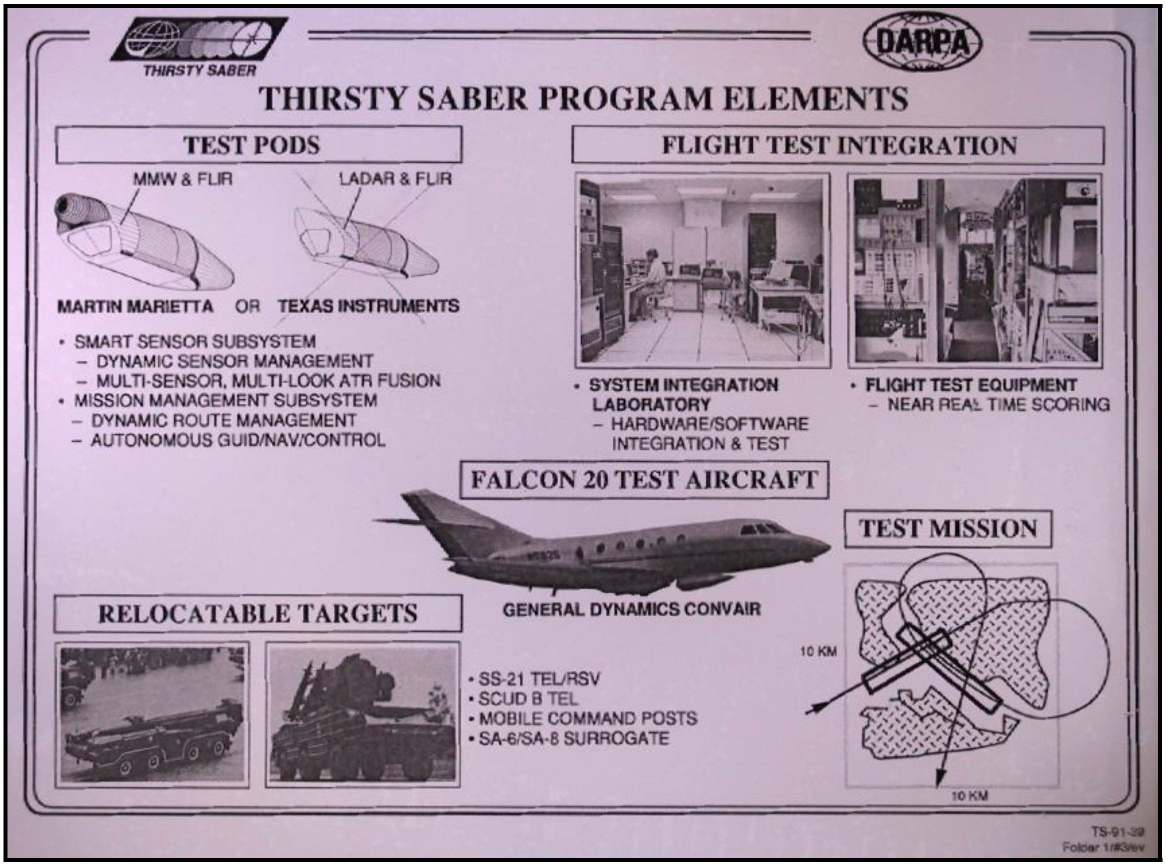

Figure V-8. Thirsty Saber Concept

The concept of Thirsty Saber was to put sensors and weapons in the target area at the same time, to attack the targets as they appeared. This was believed the only useful way to attack time-critical (fleeting) targets. The program focused major effort on killing the targets where they were hiding and on demonstrating ATR capability through camouflage, partial canopy, and up to 50% obscuration.

Throughout the SWP/TS program, critics complained about the cost of the smart bus. Consequently, the program began to focus on cost per kill rather than on the cost of the weapon itself. This argument was and will remain valid as long as this class of targets is considered to be important. The program developed quantitative analyses on the cost per kill and qualitative arguments on the cost of NOT killing enemy mobile missiles. Unfortunately, as will be described in more detail later, Desert Storm proved just how troublesome and expensive to us these targets could be.

In 1991, an accelerated, fully packaged version of Thirsty Saber was proposed in response to Desert Storm. Dubbed Thirsty Warrior (TW), the effort would have bypassed the normal DARPA hesitation in fully integrating a flyaway version of this complex system. There was substantial, high-level support in the initial few months, in spite of significant funding needed to fully integrate the TS capabilities into a cruise missile. Impetus for this program concept waned rapidly upon the sudden end of the war. Subsequently, the DARPA Warbreaker program described below reexamined the mobile target problem.

Damocles

In 1988, DARPA sponsored the development of a loitering submunition using Balanced Technology Initiative (BTI) funding. Damocles was complementary and in some ways a competing alternative to TS. It was a self-guided, loitering, single projectile with a multi-sensor suite and brain; it was designed to search 1 square kilometer (over 100 times the area that Assault Breaker munitions were designed for) and would kill only one target. Although a smart bus, such as TS, could deliver it, it was also compatible with command-guided delivery systems such as ATACMS and MLRS. It was designed to attack critical mobile targets such as the Scud. Because of its smaller search area and mission time, it could not handle the fleeting or shoot-and-scoot mobile missile for which TS was designed. If used in ATACMS or MLRS, the target uncertainty would have to be commensurate with the smaller search footprint of Damocles, thus placing a greater burden on remote sensing and mission planning.

The Damocles sensor suite consisted of infrared imaging and millimeter wave range radar. This together with the Aladdin computer made Damocles the most sophisticated submunition designed up to that point in time—a miniature TS for single target kill. Damocles continued into the early 1990s and served as a model for the new class of loitering weapons such as LOCAAS and BAT P3I.

Warbreaker

The "Great Scud Hunt" of Desert Storm proved that we could not find Scuds with manned aircraft in spite of the massive sortie rate. Because of the enemy air defense systems, allied manned aircraft were forced to fly too high, well above their useful sensor ranges for viewing targets of this size. Other data show that humans are not good at search in high stress, multi-tasking scenarios, even with good sensor inputs. Thus, it can be argued that Allied aircraft would not have found their targets any better even if they had been able to fly lower.

A key experiment in TS showed that good search results are not necessarily compatible with manned flight. The Martin Marietta SWP payload was flown in a manned, surrogate aircraft. The sensor management suite controlled the aircraft as if it were in a cruise missile (with manual override of course.) Many of the technical crew became ill due to the unusual flight behavior of the sensor management suite. Furthermore, humans viewing the sensor output could not find the targets.

The support for Thirsty Warrior rapidly evolved into a new program concept—Warbreaker—that proposed to take a fully integrated approach to Scud hunting and the mobile target problem. An advisory group reported to the director of DARPA to oversee the work of the Tiger Team led by a DARPA manager and an external chairman (Dr. Larry Lynn). Many DARPA PM's and offices were involved in sorting through the options. All ideas were fair game. The top down guidance was to assume nothing, including Thirsty Saber/Warrior.

The program evolved into an architecture for finding the Scuds rather than a complete reconnaissance/strike capability. It was felt that if DARPA solved that hunt problem, the Air Force and Navy would figure out how to kill the targets. The success of JSTARS SAR/MTI in Desert Storm made it a prominent candidate for tracking all movers. This was combined with the idea of developing a birth-to-death catalog of movers and shooters. Warbreaker lasted about two years and gradually shifted to simulation and modeling associated with the surveillance and acquisition of critical mobile targets.

SUMMARY

This review of precision weapons closes with a short report on the outcomes of the specific efforts mentioned earlier, a brief discussion of the barriers to the fielding of smart weapons, and suggestions on where the future lies.

Where are they now?

- Automatic Target Recognition (ATR) for infrared sensors. A first generation of ATR for thermal imaging systems is in the field, with improvements on the way. There are plans to equip the LANTIRN FLIR on the F-16 with ATR for pilot alerting and cueing. The FLIR on the Comanche helicopter will use ATR algorithms of the type developed and evaluated under the DARPA programs of the 1980s. In response to a special 1996 DSB task force on ATR, the DDR&E funded an ATR evaluation program that duplicated many aspects of the DARPA effort of the 1980s. The OSD program concerned itself not just with ATR for infrared imaging, but for all primary-imaging sensors including synthetic aperture radar, laser radar, hyperspectral, and multi-sensor combinations. Many of the people involved in the earlier DARPA effort helped formulate the program and execute it.

- Infrared Focal Plane Arrays. The Marines and the Army are equipping their combat vehicles with the Driver's Vision Enhancer (DVE), AN/VSS-5, from Raytheon TI, based on a 328 x 245 element uncooled detector array, working in the 7.5 to 13 micron waveband. In addition, uncooled imaging development continues at DARPA jointly with the Army, which now sees uncooled thermal imaging as a revolution that will allow the proliferation of thermal imaging systems across a wide range of applications from seekers for smart weapons to night vision devices for target acquisition and surveillance. The Navy is considering the technology for low cost seeker modifications to existing bombs to make smart bombs by modifying dumb ones and to upgrade the Joint Direct Attack Munition (JDAM). The seeker would provide precision, autonomous attack even if GPS on the JDAM is jammed. A successful test in 2001 proved the concept. DARPA has proposed to use the technology for a loitering attack missile for the Future Combat System. Recently, high quality arrays of 640X480 promise even more applications. Furthermore, several sensor web programs, including the OSD Smart Sensor Web and the Army ATD, have focused on the technology to provide micro thermal imaging cameras for their night imaging needs.
- Millimeter Wave and Synthetic Aperture Radar and ATR. The Apache Longbow uses millimeter wave ATR algorithms developed and evaluated with DARPA support of the 1970s and 1980s. It was the first ATR fielded in the 1990s. Although DARPA, industry, and the Services explored the use of millimeter wave seekers quite actively, there are none in the field, and interest in such seekers has waned due in large part to the emergence of laser radar seeker concepts. Synthetic aperture radar (SAR) technology has progressed well, but not for smart weapons applications. The geometry and image formation path for SAR are not conducive to natural weapon flight, and, the electronics needed to form the SAR image and find targets using SAR ATR cannot yet be packaged in weapons any smaller than a Tomahawk cruise missile. Instead, SAR ATR is slated for deployment in JSTARS. Although JSTARS operates at X-band, it uses the kind of template matching millimeter SAR ATR algorithms developed by DARPA in the 1980s. JSTARS will be the first deployment of modern, 2-D ATR. Advances in electronics packaging and computer technology will eventually permit small SAR imaging systems in packages weighing 20–50 pounds at X-band, even smaller at Ka-band. This may result in the emergence of smart weapons developments with SAR seekers.
- Imaging Laser Radar (ladar) and ATR. The DARPA-sponsored experiments at MIT/LL explored the full dimensionality provided by ladar sensors. Today, many weapons developments are considering ladar as the primary seeker element because of its robust ATR, reasonable performance in adverse weather at short ranges, and small optics. In particular, all loitering weapons developments, including LOCAAS and Tomahawk upgrades, are planning to use ladar *if* they make it to the field. In addition, ladar and its ATR are currently the subject of major DARPA programs, including the Future Combat System, Jigsaw (sensor improvements), and the 2002

new start E3D (high resolution ladar ATR—3-inch pixels). Ladar and its 3-D imagery should be one of the key enablers for the next generation of ATR. The loitering weapons that plan to use it will search large areas for scattered targets; ladar ATR greatly reduces the false alarm and makes such weapons concepts viable. Ladar is being aggressively explored by DARPA and the Services to penetrate foliage. The new "flash" ladar technology in development at DARPA and elsewhere should help—flash ladar forms images at 30 Hz rather than by scanning.

- Computing hardware for Smart Weapons. The high-speed numerical processors developed for Aladdin are used today. But the stunning growth of commercial computer speed and memory have eliminated the need for custom ATR processing hardware, except in the most demanding applications.
- Global Positioning System (GPS). The JDAM precision-guided bomb uses GPS to precisely navigate to its targets. This precision-guided bomb has been a resounding success in recent combat missions. In spite of emerging concerns for jamming, GPS is being planned for use in most future smart weapons and in just about every sensor and platform associated with targeting and delivery for them. Although jamming is a real problem, modifications and upgrades will erode the threat. Weapons designers often use GPS simply to update the inertial navigation unit on the weapon when jamming is not detected.
- Assault Breaker. As mentioned earlier, the particular smart submunitions used in the final AB demonstration never made it to the field. Only BAT and SADARM have come close, and their developments have experienced frequent terminations and restarts. Both are being considered as payload options for the loitering upgrade for the Tomahawk cruise missile.
- Tankbreaker. Tankbreaker technology, incorporated into Javelin, may be used by some of the competitors in the Army Common Missile program. Because this program is in a highly competitive phase, it is hard to predict if any additional variations on the theme will ever be fielded. In general, cooled focal planes for missile seekers may face stiff competition from uncooled focal planes.
- Smart Weapons and Thirsty Saber. These concepts live on in the Cruise Missile Real-Time Retargeting Program. The proposed Tomahawk upgrade would field a weapon system capable of searching 100 square kilometers or more in its search for mobile missiles and other time critical targets. It may carry multiple submunitions for multiple kills of targets found along its flight path. Some of these could be smart munitions such as BAT, SADARM, or Damocles.
- Warbreaker. Warbreaker was never implemented. The idea of basing SAR/GMTI sensors in space rather than on air platforms emerged late in the Warbreaker program. A few years after Warbreaker ended, space-based radar came to life in a new DARPA initiative, Discoverer II (See Chapter VII). Discoverer II proposed to blanket the world from space with rapid revisit SAR/GMTI capability. This was to have been

achieved by reducing the cost of the satellites to the point where anywhere between 24 and 48 balls could be maintained aloft. However, Congress canceled Discoverer II in FY 2000.

- Damocles. This smart munition concept has served as the model for subsequent long loiter munitions. Until the advent of Damocles, the life cycle of a smart munition was supposed to be a few seconds. Damocles proposed to last several minutes while it searched an unprecedented large area. Damocles is dormant as a weapon concept but its seeker test bed is being used to collect multi-sensor data for the OSD ATR evaluation program.[14]

In spite of all these various successes, there are few smart weapons in the field. The JDAM, Hellfire missile, and laser-guided bomb are precise but dumb; *they do not pick their targets*. The closest thing to truly smart weapons about to enter the field are BAT and SADARM, and after 20 years of development they ride programmatic swings from funded to dead every year or two. Why is it so difficult to field smart weapons? A few of the reasons are discussed below.

- Smart weapons reduce force structure. Smart weapons reduce the need for manned platforms by providing higher kill ratios per ton of ordnance delivered in battle. Hence, they threaten the core manned platforms of the Air Force and Army Services: tanks and jets.
- Smart weapons are perceived to be too expensive. The cost of individual smart weapons can be deceptive, as the cost per kill for smart weapons may be lower than any other method of attack. The cost of delivering current weapons is viewed as sunk cost; the infrastructure exists; therefore it costs nothing. It is a false economy.
- They are not smart. This objection is often based on inflated expectations and demands on smartness. It is expected that smart weapon will achieve 90–100% reliability, effectiveness, and resistance to countermeasures, which no manned system can achieve in real world scenarios. Recent conflicts highlight the well-documented facts of war: manned weapons delivery is vulnerable to deception, decoys; the danger of fratricide is always present. In December 1996, Vice Chief of Staff of the Army, General Ronald Griffith, suggested that ATR and smart weapons may actually reduce the frequency of such errors.[15]
- Smart systems are hard to evaluate. This factor may become a dominant barrier in the coming decades. In fact, it is possible that loitering attack systems such as Thirsty Saber and its successors will remain in development for up 20 years while the development community figures out how to provide users with evaluation tools that

[14] Meeting 3/28/02 with Mr. Jeffrey Paul, Acting Director, Sensor Systems, ODUSD(S&T).

[15] General Griffith was reviewing the DDR&E briefing package on ATR in preparation for the Joint Requirements Oversight Council (JROC). He cited smart weapons immunity to fatigue and emotional response.

can test them over their full functional range with statistically meaningful results. Consider the relatively simple task of evaluating JDAM. It either goes to its coordinates and detonates or it does not. Compare that with LOCAAS, which may fly up to a half-hour, search 50 square kilometers, and have ample opportunity to attack false targets. The problem will worsen as technologists integrate more smartness into weapons, thanks to steady advances in computers, software, and sensors.

- Smart weapons change doctrine. As we evolve to smarter and smarter weapons, loitering attack systems, and similar ground-based robotic capabilities, it may be necessary to change doctrine and force structure. Increasingly, joint operations may be needed to exploit smart weapons. It is always harder to introduce a system under these circumstances. For example, Tankbreaker entered the field because it replaced the existing Dragon Missile, a system the Army owned and knew how to use. On the other hand, LOCAAS is a new kind of weapon that requires a different kind of treatment. It is not a bomb, not a missile, not a loitering aerial mine. Its attack may occur up to a half-hour after it is launched. Just knowing what each LOCAAS does in a battle requires new thinking.[16]
- The technology is not ready. Building smart loitering weapons is hard. Some concepts will be harder to implement than others, and maturation may take longer than proponents believe. A corollary to this factor is that the number of available technology options is constantly increasing, making it even harder to choose the solution and stick with it. The fact the development cycle is inherently long compared with the pace of modern technology tends to compound the problem.

Future Directions for Smart Weapons—A Battlefield Nervous System

Recent conflicts, from Desert Storm to Afghanistan to the most recent Iraq conflict, have highlighted the need for lightning response to find and kill time-critical, mobile, or fleeting targets. The US capability in conventional warfare, with its central theme of overwhelming air dominance, has forced our enemies to hide most of the time. Targets present themselves briefly in order to survive. This natural response forces us to consider capabilities afforded by systems such as Thirsty Saber and its successors. It forces us to seek response times measured in seconds and minutes, to seek widely dispersed targets, and to delegate the attack to assets close to the targets while maintaining confidence that what we are shooting is what we are supposed to be shooting. For example, the presence of precision weapons encourages enemies to hide among non-combatants. To solve this problem, a weapon must be both precise and smart.

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16 See Richard Van Atta, Kent Carson, Waldo Freeman, *Small Unit Precision Combat: Attacking Elusive Targets in Complex Terrain*, Alexandria, VA: Institute for Defense Analyses, March 2003, for an example of how such capabilities might enable entirely new force concepts.

Today, there is a rapidly emerging awareness in the military that the pace and scale of warfare is becoming almost personal and instantaneous. In other words, individuals and small groups of elusive combatants have become a major target of interest. No longer can we rely on the enemy to fight as he did in Desert Storm, with massed armor and conventional troop deployments. Ten years later, the US is fighting guerilla warfare with theater-based assets designed to work in target rich environments and scenarios where the enemy moves on a time scale measured in hours or even days. In an attempt to deal with this, we have seen Hellfire missiles fired from the Predator UAV, a conceptual leap. It also puts the targeting in the hands of ground forces. Perhaps we are now evolving to the true loitering, supervised attack systems that we will need in higher intensity scenarios involving many on many combatants.

Along these lines, the Army Science Board recently reported a grand vision for the Objective Force Warrior that places lethality in the hands of the lowest echelons.[17] It wraps network-managed weapons, loitering UAVs, and UGVs around the squad, platoon, and company. A touch screen personal digital assistant could become the dismounted soldier's primary weapon. The DDR&E Smart Sensor Web Program demonstrated in January 2002 that local, invasive sensor arrays and loitering overhead UAVs could greatly enhance platoon effectiveness in urban warfare scenarios. Ultimately, local sensor webs for intelligence, surveillance, and reconnaissance (ISR) must be coupled to local weapons. It is probable that technology will permit fielding of new kinds of personal weapons that can be integrated with local ISR. These would belong to and be launched by the soldier. In the meantime, it is reasonable to expect that increased endurance UAVs, UGVs, and multi-mode mobility weapons delivery options will be considered for placing responsive firepower in the hands of the dismounted soldier for precise delivery when and where it is needed.

Future possibilities continue to evolve. Technology now permits us to conceive of low cost, invasive sensor fields for urban terrain and tanks under trees. Technology now allows sensors to store gigabytes of data in memory chips the size of postage stamps. Camcorders, digital cameras, and miniature uncooled thermal imagers weigh only a few ounces and provide full VGA format imagery or better. New power sources and engines may permit the fielding of micro UAVs with up to an hour endurance and handheld UAVs with several minutes flight time. Wireless modems and adaptive networks can provide information to the lowest levels on daylight readable, personal digital assistants. The technology will enable combatants to establish mobile and adaptive areas, perimeters, and even buildings that are wired for ISR and lethality, as needed.

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17 Elizabeth Book, "Competition Gets Under Way for Objective Force Warrior," *National Defense*, May 2002. <http://www.nationaldefensemagazine.org/article.cfm?Id=801>.

The sensor webs, coupled with local, distributed, web–based computing may form the basis of a battlefield nervous system, and the weapons may become the defense mechanisms for this nervous system.

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VI. UNMANNED AERIAL VEHICLES

Richard H. Van Atta, Jack Nunn, Alethia Cook, and Ivars Gutmanis

OVERVIEW

Unmanned aerial vehicles (UAVs) encompass a vast range of vehicles operating below space: balloons, gliders, rotorcraft, and multi-engine unmanned aircraft.[1] This chapter concentrates on powered UAVs used by the military that employ either on-board guidance or respond to remote guidance instructions. Such UAVs have been deployed for a variety of missions, including:

- reconnaissance (short-term observation of an enemy's operations, using cameras, radar, and other sensors)
- surveillance (longer-term observation)[2]
- electronic intelligence
- target acquisition and designation
- target destruction (using on-board weapons)
- battle-damage assessment
- communications relay
- chemical and biological warfare detection.[3]

In 1974, the DoD outlined three broad groups of what were then termed "remotely piloted vehicles" (RPVs). The first was the High-Altitude/Long Endurance aircraft. These RPVs were considered as substitutes for the long-range manned aircraft (EC-121, U2). This mission required "large airframes (approaching the size of small tactical aircraft), long-range, high-altitude, and large payload capabilities…payloads should include passive and active

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1 Some of these vehicles that could be piloted from another location were termed "remotely piloted vehicles" (RPVs), but that term now appears to be subsumed under the term "UAV." It is useful to note that one major difference in UAVs and RPVs is that RPVs have been defined by the DoD as "unmanned, powered, airborne vehicles which are controlled by man." Robert Parker, Statement before the Senate Armed Services Committee, 1976, Y4.AR5/3:P94/6/976/pt 10.

2 Many sources treat reconnaissance and surveillance as essentially the same operation. For the purpose of this analysis, the authors have adopted the distinction made by the Congressional Budget Office because UAVs can be specifically designed to perform one task or the other. Development and operational challenges for UAV design are entirely different based on whether the vehicle will be employed in short or endurance missions.

3 Congressional Budget Office, *Options for Enhancing the Department of Defense's Unmanned Aerial Vehicle Programs,* Washington, DC: Congressional Information Service, September 1998, pp. 14–17.

electromagnetic sensors,…”[4] The second category was Medium-Scale RPVs. These were described as useful for multi-missions, including low-altitude, reconnaissance, electronic warfare (EW), and strike. They were “in the 500- to 5,000-pound class and characterized by high speed, maneuverability, terrain avoidance capabilities, relatively large payloads, and an ability to operate during adverse weather conditions day or night.”[5] The third major category was the Mini-RPV, which was described as:

> ...scaled upward from model airplane technology and as such will be characterized by low-speed, limited endurance, small payloads and operating at relatively low altitudes, day or night under adverse weather conditions. They are designed to be cheap and easily maintained, thus making it possible to procure large numbers.[6]

These three classifications continue to exist and form the basis for modern UAV developments. This chapter outlines the development of UAVs with particular attention to the role that DARPA has played in these developments.

DEVELOPMENT HISTORY

The United States has pursued the development of precursors to the modern UAV for military purposes since World War I. Military development programs have been undertaken with the objective of increasing the effectiveness of forces by fielding aircraft that could operate in environments that were too hostile for human pilots. Their use has been both driven and limited by available technology. For example, the lack of good, autonomous sensors limited their early reconnaissance role. As a result, most of the early systems were designed for attack. Thus, during World War I, the British, applying an improved understanding of electromagnetic effects, designed and built both ground and air remotely controlled systems including a “guided, explosive-laden, Unmanned Air Vehicle (UAV) to glide into German airships.”[7] The US began its own developments of UAVs at this time and by 1919 “had built an unmanned explosive UAV controlled by gyroscope and aneroid barometer.”[8]

Following WWI, there were further developments of radio-controlled UAVs for use as both guided bombs and as targets for anti-aircraft practice. In Germany these advances

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4 US Congress, testimony before the Senate Armed Services Committee, March 1974, Y4.Ar5/3:P94/6/1975/ pt. 6, p. 3038.

5 Ibid.

6 Ibid.

7 Kenneth Macksey, *The Penguin Encyclopedia of Weapons and Military Technology from Prehistory to Present Day*, New York: Viking Press, September 1994, p. 292.

8 Ibid.

ultimately led to the V1 cruise missile. The Americans and British, responding to air warfare doctrines that emphasized the superiority of massed, manned bombing campaigns, made only limited use of UAVs as guided bombs. But there were some advances on the allies' side. During the Second World War, for example, some older B-17s were converted to

> …BQ-7 radio-controlled flying bombs in Project Aphrodite. These aircraft were stripped of armament, filled with 9 tonnes (20,000 pounds) of explosive, and fitted with radio control. They were to take off with a pilot and copilot who directed them toward the target and then bailed out. The BQ-7s were to then be directed to the target by a controller aircraft. The cockpit of the BQ-7 was cut open at top to make bailing out easier. The BQ-7s were intended to be used on V-weapon sites in northern France.[9]

They were reportedly a failure since only a few of the missions launched had ended in success. Despite these wartime failures, after the war additional B-17s were modified as radio-controlled drones. These QB-17Gs were operated from other B-17s modified as manned DB-17G directors. Reportedly, "the QB-17G was far more satisfactory than the BQ-7, and was used to collect atmospheric samples from the nuclear-bomb test at Eniwetok Atoll in July 1946, as well as at later weapons tests into the early 1950s. The QB-17Gs also served as aerial targets through the 1950s, with the last of these drones shot down in 1959."[10]

As the Air Force introduced the B-47 into its manned bomber inventory, some of them were configured as UAVs. One idea was to convert a few B-47Bs into unmanned "MB-47B" drones that would carry an H-bomb. However, after further study the scheme was deemed to be impractical and was canceled.[11] Other B-47Es were converted to "QB-47E" target drones in 1959 and 1960. "These aircraft were radio-controlled, and included such interesting features as self-destruct charges and arresting gear to assist in landings. They also carried pods mounted on the external tank pylons to help in scoring weapons tests. The last of these QB-47Es were retired in the early 1970s."[12]

US UAV development efforts were spurred in the 1950s by both the military threat and by technology developments. At the strategic level the US was very concerned about what was going on behind the closed borders of the Soviet Union. The US was launching balloons, manned aircraft, and, ultimately, satellites to provide intelligence information. Several of the manned flights were shot down, the most famous being the U2 piloted by Gary Powers. It was

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9 Greg Goebel, "Air Vectors, Fortress Oddballs," <http://vectorsite.net/avb172.html - m4>.

10 Ibid.

11 Goebel, <http://vectorsite.net/avb47.html>.

12 Ibid.

thought that unmanned aircraft might reduce risks while providing good pictures. Although on-board sensors were probably adequate to support such an unmanned role, the aviation technology was inadequate to allow the deep penetrating flights that were conducted with the U2s.[13] The unmanned air vehicles of the day did not have the altitude, speed, and range necessary to survive in Soviet airspace and perform U2-type missions. But by the early 1960s, the Air Force, working with Ryan Aerospace, was developing an unmanned reconnaissance aircraft with a range of 1,200 miles and an operational altitude of 55,000 feet. Improved models became operational and were used over North Vietnam and southern China.[14] In the late 1960s, the Air Force developed the Compass Arrow (AQM-91A), a high-flying, unmanned photoreconnaissance aircraft. It was designed to fly deep into China. It could cruise at nearly 15 miles altitude while taking photos showing ground details as small as 1 foot in size. After air-launching from a DC-130E, Compass Arrow navigated automatically, but it also could be flown manually by an operator in the launch aircraft. Because of changes in the political environment the aircraft was not deployed.

Tactical use of UAVs became focused when the Vietnam War challenged the military to reduce the costs in men and aircraft of making aerial reconnaissance missions deep behind enemy lines.[15] The Firebee, developed by Teledyne Ryan, was originally designated the Q-2 and later designated the BQM-34. It was a high-speed target drone with a range of 600 miles.[16] It was used primarily for testing newly developed missiles and for training fighter-interceptor pilots. It became the standard jet target for scores of uses by the Air Force, Navy, and Canadian forces and became the basis for the evolution of UAVs. Over 6,500 were built. These aircraft were also fitted with sensor packages and used operationally in Vietnam.

In the mid-1960s, Teledyne Ryan, using the subsonic "Firebee I" design, developed a supersonic version for the Navy and the Air Force. The Air Force ordered 99 BQM-34Fs and, by February 1974, started using them. The BQM-34F was rocket-boosted from a short rail ground launcher or dropped from a C-130E aircraft. They were normally recovered with the Mid-Air Retrieval System (MARS), which included a specially equipped helicopter that "snatched" the target while it descended under its parachute. If the BQM-34 landed in water, it could float for several hours until it was recovered. The BQM-34F carried an assortment of electronic devices

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13 Ben Rich & Leo Janos, *Skunk Works,* reports on the loss of US aircraft and airmen on the perimeter of the Soviet Union and describes in detail the difficulties of flying the U2 missions during the late 1950.

14 Goebel, <http://www.vectorsite.net/twuav3.html>.

15 Congressional Budget Office, *Options for Enhancing the DoD UAV Program*, p. 13.

16 Wright Patterson AFB Museum of Flight Web site,<http://www.wpafb.af.mil/museum/>.

to enhance its radar image, permit flying as low as 50 feet, control it from up to 200 miles away, "score" the missiles fired at it, and telemeter information to and from it during flight.[17]

Another variant of the Firebee, the AQM-34L reconnaissance drone built by Teledyne Ryan, was developed from the BQM-34A. It was a jet-powered, subsonic target drone first produced in 1960. It is one of a series of Remotely Piloted Vehicles (RPVs) used for combat reconnaissance during the Vietnam War. The AQM-34L was air-launched and controlled from a C-130 director aircraft and flown on low-level photographic missions over North Vietnam. After a mission, the RPV was directed to a safe recovery area where its parachute was deployed and the aircraft was either retrieved in mid-air by helicopter or recovered from land or water.

There were a number of other demonstration programs using Firebee-derived UAVs. These included flak suppression, chaff dispensing, target designation, and weapons delivery roles, but these missions were never performed operationally. UAVs also were tested dropping bombs and firing the electro-optically guided Maverick missile. However, although these demonstrations were successful, termination of the Vietnam conflict ended the expanded roles of UAVs.[18]

The end of the conflict was also marked by a massive drawdown of US military forces, including the elimination of Air Force UAV organizations in 1976. The Air Force interest moved to cruise missiles and away from the traditional UAV. Table VI-1 provides data on some of the more prominent US UAV efforts of the 1960s and 1970s.

Table VI-1. Selected Early RPV/UAV Programs

Program	Period	Description	Status
Dash/Snoopy	Late 1960s	Rotorcraft RPV initially for anti-submarine, but terminated. Designated Snoopy and used by Marines in Vietnam	Terminated/ Retired
Firebee (Variants)	1964–1979	Reconnaissance drone first used by the Air Force in Vietnam	Retired
NITE PANTHER NITE GAZELLE	Late 1960s	Electronics packages used on rotorcraft RPV in Vietnam, but had reliability problems	Retired
YQM-94A Compass Cope	1972–1979	High altitude, long endurance RPV	Air Force decided not to purchase
Praeire/Calere	1972–1976	Mini-RPV built by Ford Aerospace. Praeire technology purchased by Israel and evolved	Evolved into Pioneer

Source: Authors' modification and update of a table in Congressional Budget Office, *Options for Enhancing DoD UAV Programs*, September 1998, pp. 12–13.

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17 William Wagner, *Lightning Bugs*, Fallbrook, CA: Armed Forces Journal International, 1982.

18 Goebel, <http://www.vectorsite.net/twuav.html>.

DARPA's Early UAV Role

DARPA has been involved in UAV development since the 1960s. It has conducted work on all aspects of the vehicles including structures, propulsion, guidance, payload sensors, communications, and operations. For almost three decades it investigated relevant enabling technologies that were incorporated in the increasingly sophisticated unmanned air vehicles. Finally, it pioneered new contracting processes that assisted in the acquisition of the research for the technology although not in the actual acquisition of the resulting products.

Early Efforts

DARPA was a pioneer in the development of Mini-Remotely Piloted Vehicles (Mini-RPVs), transitioning many of the technologies developed into later RPV and UAV programs.[19] Many of these were classified and some remain so.[20] One of its first major unclassified efforts was "to develop payloads for the Navy drone anti-submarine helicopter (Dash), including communications and guidance packages, day and low-light-level television…"[21] The Dash, however, proved difficult to handle because of electromagnetic interference aboard ships and was finally abandoned by the Navy in 1970. But, configured with the low-light-level TV system, it was renamed "Snoopy" and used by the Marines in Vietnam.[22] In the late 1960s, as a result of an urgent request from the field, DARPA's Advanced Sensor Office (ASO) undertook an effort to improve Snoopy.[23] The new payloads varied and included a number of systems in addition to the existing communications and guidance and day and low-light-level TV to include moving target indication (MTI) radar, a hypervelocity gun, a laser designator rocket system, and a variety of other weapons. Two experimental systems—NITE PANTHER, designed to demonstrate remote target acquisition with sufficient accuracy for fire control, and NITE GAZELLE, intended as a standoff, precision strike system—were both used successfully for training and operations in Vietnam. However, both were reportedly plagued by mechanical reliability problems.[24]

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19 *Defense Advanced Research Projects Agency Technology Transition*, Arlington, VA: Defense Advanced Research Projects Agency, circa 2000, p. 102 (downloaded from <http://www.darpa.mil/body/pdf/transition.pdf>).

20 Interview with Mr. Bradford M. Brown, President, Pioneer UAVs, Inc., January 2002.

21 Sidney Reed, Richard Van Atta, and Seymour Deitchman, *DARPA Technical Accomplishments: An Historical Review of Selected DARPA Projects*, IDA Paper P-2192, Vol. I. Alexandria, VA: Institute for Defense Analyses, 1990, pp. 28-3 to 28-4.

22 Ibid.

23 Ibid. This was in response to a Zap Channel request. The Zap Channel was a quick-reaction mechanism used for DARPA to respond to urgent DDR&E requests for Vietnam support. AO 1162, 2/68.

24 Ibid.

Building on Success

Despite their reliability shortcomings, the technical successes with the NITE PANTHER and NITE GAZELLE sensor programs led the ASO to the concept of the "extended battlefield." The initial step was employing tethered balloon-borne systems: Egyptian Goose had an MTI radar for tracking. The Grandview employed TV-bandwidth communications. Tests of the NITE GAZELLE extended range system were conducted in the early 1970s at Nellis Air Force Base. These demonstrated the capability to find and designate targets for attack over 100-nautical mile ranges. The payload in NITE GAZELLE used in these trials included a rocket with a laser angular rate seeker. This was reportedly the beginning of work by Martin Marietta which led eventually to the seeker used in the Army's Cooperhead laser-guided munitions. The NITE GAZELLE was an expensive system. The first one cost over $10 million to develop. Its reputation for reliability difficulties appears to have discouraged large-scale use.[25]

In spite of the reliability problems experienced by NITE GAZELLE, the system provided a basis for further development. The characteristics DARPA had integrated in the system were judged to be desirable in a 1971 Defense Science Board study of RPVs.[26] This DSB study led to further development efforts within DARPA. The Agency intensified efforts during the early 1970s toward development of lighter, more compact, higher performance and lower cost electro-optical sensor systems for use in Vietnam, both on the ground and in the RPVs.[27]

The idea for a Mini-RPV Program emerged in 1971 as a result of an assessment of the potential for the development of smaller sensors and guidance packages for unmanned vehicles. In 1971 Dr. John Foster, the Director of Defense Research and Engineering (DDR&E), during a briefing to him by DARPA recommended that the DARPA RPV program move from expensive and complicated helicopter platforms, such as that for NITE GAZELLE, and instead focus on the use of lightweight, rugged, inexpensive model airplane technology. The DARPA Mini-RPV program began in early 1972 as an effort toward the type of lightweight, compact, low-cost, low-speed, sensor/laser target designation system that had been recommended by Dr. Foster and the DSB.[28] DARPA described the program objectives as trying to "evolve new Service options for low-cost, low-speed, small, unmanned aircraft for missions such as reconnaissance, target

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25 Ibid., pp. 28-3 to 28-4.

26 Ibid.

27 Ibid.

28 George Heilmeier testimony, US Congress Senate Committee on Armed Services, FY 78 Authorization for Military Procurement, Research and Development, and Active Duty, Selected Reserve, and Civilian Personnel Strengths. Part 9: Research and Development, March 17, 23, 29–31, 1977, p. 6240.

acquisition, target laser designation, or target strike."[29] The initial resulting RPV was built by Philco-Ford. It had exchangeable modular payloads. The RPV carrying the daytime TV-laser target designator configuration was named Praeire, and the same RPV carrying a lightweight FLIR and laser target designator combination was named Calere.

Praeire I weighed 75 pounds and was powered by a modified lawn mower engine. It had a 28-pound payload and a 2-hour flight time. It was an austere, low-cost system, with a cost estimate, in mass production, of $10,000/copy. The first flight of Praeire I occurred in 1973 after a joint DARPA-Army program had been started. However, there were some difficulties with performance of the Calere IR payload, requiring further development.

The Army's effort in response to the DoD initiative included, besides the joint program with DARPA, its own trials of several other types of available Mini-RPVs in a program intended to gain a better determination of requirements. It called this effort "little r." Part of the "little r" program also was a phased development effort of an entire RPV system, together with ground control and support. This led to the Lockheed Aquila, beginning in late 1974.[30]

DARPA subsequently developed the Praeire II and Calere II. These were again built by Ford and based partly on the experience with the pervious vehicles. One aim was to reduce the radar and IR signatures. Sensors and propulsion were also improved, and the flight time capability was extended to nearly 6 hours. The extended range vehicle Praeire II B had nearly twice the weight of Praeire I. An electronic warfare payload was developed. A Calere III was also produced. It included a new, lighter FLIR-laser target designator combination. The Praeire II was acquired by Israel. This technology was combined with Israel's own technology into the Mastiff system, the Scout, and finally into the Pioneer.[31]

During this same time frame, DARPA and the Air Force were also involved in a joint program, called Axillary, to develop an expendable Mini-RPV capable of loitering and attack. The Air Force followed up Axillary to a limited extent but apparently favored the Tacit Rainbow loiter-capable, air-launched guided missile for the same mission.

Overall, DARPA was very active in RPV work in the 1970s. In addition to working with the Services on specific RPV projects, it was doing a great deal of research on systems and enabling technologies. But the technology was having difficulty getting deployed. Testifying in April 1974, Robert Heeber, Deputy Director, Defense Research and Engineering for Tactical

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29 Ibid.

30 Statement of Mr. Robert Parker, Principal Deputy Director for DDR&E, Y4.Ar5/3:P94/6/976/Pt. 10, p. 5675.

31 Interviews with Abraham Karem and Bradford M. Brown.

Programs, surveyed the experience with RPVs to that date and addressed some of the reasons why more use was not being made of these vehicles. He observed that:

> …the Air Force has been quite successful with its Model 147 RPV in conducting recce [deleted] missions in SEA, but problems with command and control and recovery, resulting in rather high attrition rates, have plagued the program. The Army and Navy experienced failures in their RPV programs in the late 60s and they have re-entered the field somewhat cautiously. As a result of the Services' combined experience, a higher priority for RPV developments has not been emphasized in the past because of technical problems associated with reliability, communications, control, sensors and problems of operational concept which must be developed along with the technology if a real military capability is to be achieved.[32]

There was some optimism, however, that the Services would take on more positive efforts. Testifying in 1975, Malcolm Currie, the Director of Defense Research and Engineering, reported that DARPA had "pioneered the development and application of Mini-RPV technology proving the utility of these small airplanes and exciting a strong military interest in the subject."[33] He stated:

> Since the Services are taking over the development of the reconnaissance and laser target designation Mini-RPVs, the DARPA program will now focus on decoys and standoff weapon applications of small, low-cost airborne system technology. The basic Mini-RPV aircraft technology which makes low cost, long endurance loiterable strike systems potentially feasible has many promising applications. Such systems might be used as deployable mines, as low-cost decoys, as low-speed drones, or as strap-ons using wing-engine components, to give existing missiles a loiter capability.[34]

In the near term, DARPA planned to continue to stay involved in RPV developments. In subsequent testimony, the Director of DARPA, George Heilmeier, told the Congress that DARPA was continuing to break new ground. He stated that the FY 1976 initiatives included:

> The test of a Mini-RPV that can be missile or aircraft launched; development and test of shipboard launch and recovery techniques; battery and solar powered RPVs; mini-infrared and laser designator and range finder systems that will enable the Mini-RPV to find targets and guide weapons at night; and data links resistant to enemy jamming.[35]

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32 US Congress, testimony before the Senate Armed Services Committee, March 1974, p. 3037.

33 Malcolm Currie testimony, US Congress Senate Committee on Appropriations, Department of Defense Appropriations, FY 76. Part 1: Department of Defense. February 12, 26, March 10, 11, June 3, 1975, p. 470.

34 Ibid.

35 Ibid., p. 750.

The following year, at a time when he was expressing concerns over the relative balance in military R&D between the United States and the Soviet Union, Dr. Currie cited RPVs as one of the few areas in which the US led the Soviet Union.[36] He saw the RPV being used to help accurately locate targets for artillery and assisting in the identifying enemy air defenses for destruction.[37] In his testimony, Dr. Heilmeier elaborated on the use of Mini-RPVs as part of a distributed sensor system. He reported that with "low cost, and with secure, jam resistant data links, these systems could provide excellent surveillance of the battlefield."[38]

In 1977, Mr. Heilmeier listed a number of ongoing DARPA Mini-RPV activities and sketched out future plans. His testimony indicated that DARPA could rightly feel that it had achieved some success in the field. He reported that:

> …after developing Mini-RPV concepts and supporting technologies for five years, we are successfully completing and transitioning these technologies to the Services. In this time, new low-cost options for some critical airborne missions have been demonstrated by DARPA and accepted by the Services for specific mission evaluation. The survivability of such RPVs against air defense has been evaluated both analytically and in tests against real weapons so that Service system mission designs can be confidently pursued. Supporting payloads for laser designation, and anti-jam command and control have been successfully developed. The DARPA program will end after the final ICNS and loiter mine developments in FY 1978.[39]

DARPA reported transitioning activities in each of the Services. The Agency's reconnaissance and target designation demonstrations had evolved into the Army Aquila program (then in field demonstration). The Air Force and Federal Republic of Germany were developing the Harassment Drone directed at the air defense saturation and destruction concept pioneered by DARPA under the Axillary program. And the Navy was developing an RPV to accomplish target acquisition for the Harpoon missile and the Navy guided projectile. This RPV was built on the previous DARPA Star program, as well as DARPA sensor and communications efforts.[40] However, while these efforts looked very promising in 1977, the actual path to deployment of US RPV/UAV capabilities would prove long and difficult.

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36 Malcolm Currie testimony, US Congress Senate Committee on Appropriations, Department of Defense Appropriations for FY 77, Part 4: Procurement/RDT&E. February 3, 17, March 16, 18, 23, 31, 1976, p. 896.

37 Ibid., pp. 897–898.

38 Ibid., p. 931. Affordable, secure, jam resistant data links are still an issue for achieving low-cost UAV systems.

39 George Heilmeier testimony, US Congress Senate Committee on Armed Services, FY 78 Authorization for Military Procurement, Research and Development and Active Duty, Selected Reserve and Civilian Personnel Strengths. Part 9: Research and development, March 17, 23, 29–31, 1977, p. 6243.

40 Ibid., p. 6241.

The Agency did, however, have one rapid technology deployment response. Israel obtained DoD approval to buy several Praeire II B systems in 1977. From these systems the Israelis went on to develop their Mastiff RPV, later the Scout and the Pioneer. This last system came back to the United States with purchases by the Services in the 1980s.[41] The Israelis used very simple and cheap drones to good effect to destroy Syrian air defenses in Lebanon's Bekaa Valley in 1982. Their success inspired then Secretary of the Navy John Lehman to push for his Service to acquire UAVs, primarily to support targeting by, and conduct battle-damage assessment for, US battleships.[42] While not identical to Praeire II and incorporating independent Israeli research, these Israeli developments were certainly influenced by the DARPA-developed technology.[43] Once in Israel, there was reportedly no collaboration with DARPA.[44]

Developing Enabling Technologies

DARPA devoted significant technology effort toward developing and demonstrating enabling technologies that would allow the full development and deployment of RPV/UAV. Asked to assess the DDR&E (which would include DARPA) role and responsibility in RPVs in March 1974, Dr. Currie responded:

> The role of DDR&E is the same for RPVs as any other weapon system development. Exploratory and early Advanced Development of sensors and related hardware is monitored by the Deputy Director (Research and Advanced Technology). As specific programs, based on that work, are definitized and become program element budget items in Advanced Development or Engineering Development they must be approved by DDR&E. Program Memorandum are prepared, coordinated and signed. The purpose of these Program Memorandum is to establish a contract between the service sponsor and DDR&E regarding the development plan schedule and funding. This enables DDR&E to contain each RPV program within specific limits, achieve specific goals, and prevent redundant efforts or systems proliferation.[45]

In 1975, DARPA's work in such activity was principally devoted to "Mini-RPVs for operation in the 250- to 300-kilometer range, applications, ship deployable RPVs, and advanced payloads that included communications jammers, direction finding, TOA and such supporting

41 Pioneer was procured starting in 1985 as an interim UAV capability to provide imagery intelligence (IMINT) for tactical commanders on land and at sea (originally launched from Navy Iowa-class battleships). Interviews with Dr. Karem and Mr. Brown.

42 Congressional Budget Office, *Options for Enhancing DoD UAV Programs,* p. 13.

43 Reed et al., *DARPA Technical Accomplishments*, pp. 28-5 to 28-7.

44 Ibid., Interview with Bradford Brown.

45 US Congress, testimony before the Senate Armed Services Committee, March 1974, p. 3035.

technologies as reduced observables, propulsion, stabilization, and data links."[46] Some of the specific activities identified during this period are listed below.

Sensor Developments

DARPA was involved in projects developing sensor packages, which could provide near or real time data links between the RPV and the user. This required target acquisition and recognition at speeds that were particularly difficult with high-speed, low-altitude RPV.[47] The outcome of DARPA's target acquisition data system, the Remotely Piloted Aerial Observation Designation System (RPAODS), transferred to the Army in 1974.[48]

Radar

Small, lightweight, high-performance radar was tested for use on a Mini-RPV. For example, DARPA supported development of the first Mini-RPV high-performance MTI radar. Weighing 150 pounds, it had a range of 15 kilometers and could recognize different classes of surface vehicles and helicopters.[49]

Emitter Locator

DARPA developed a miniature emitter location system designed to fly in a Mini-RPV. Since the operational characteristics of this system and the RPV radar are complementary, a program was initiated to combine the two into a single system to locate, identify, and track enemy targets.[50]

Command and Control

DARPA conducted a number of efforts aimed at improving the command and control of RPVs. In DoD's view "the singular contribution that it made" [between 1971 and 1974] was "sponsorship of a stabilization system, which allows a mini-RPV to be flown stably with only intermittent control. In a sense it provides a very low cost autopilot capability with this class

46 Ibid., p. 3043.

47 Ibid., p. 3041.

48 Ibid., p. 3046.

49 US Congress, Testimony of Director, DARPA, before the House Armed Services Committee, p.1072. Y4.Ar/2a/987-88/71.

50 George Heilmeier, Testimony, US Congress Senate Committee on Armed Services, March 17, 23, 29–31, 1977, p. 6240.

aircraft without requiring all of those things that we associate with autopilots, gyros, and accelerometers, and such expensive components."[51]

In addition to on-board command and control developments, it also worked on the development of anti-jam data links

> …which would permit continued operation under all but the most severe jamming scenarios and which would be small, light and cheap enough to be used in the RPV. The required AJ margin was achieved. This unique approach has met or exceeded all its design goals and will result in a complete RPV communications package that weighs less than 15 pounds and will cost about $7,000 in production quantities. As part of the RPV data link program, it was necessary to pay special attention to the video data link. Standard TV signals have such a wind bandwidth (25 Mbps or more) that the direct application of spread-spectrum modulation is virtually impossible. Instead, DARPA initiated a program to reduce the bandwidth of the TV signal by removing both the spatial and temporal redundancy.[52]

The Agency helped develop the Integrated Communications-Navigation System (ICNS), in which automatic acquisition, resistance to jamming, aircraft location, and the ability to pass both digital data and video signals were demonstrated. The program was transferred to the Army for testing in both manned and unmanned (Aquila) aircraft in CY 1978. At the time, DARPA reported: "The ICNS is a system in which modulation and adaptive antennas have been successfully combined, and it represents the state-of-the-art in anti-jam technology, both as to performance and as to size, weight and cost."[53]

Materials/Structures

DARPA was involved in a number of materials and structures projects over the period. Much of this had to do with making the aircraft less detectable. Efforts to reduce the radar image were discussed in the early 1970s, but less was said about those efforts, as Stealth became a reality. RPVs were reconfigured to reduce the detection of heat emissions.[54] The aircraft were designed to reduce radar detection. Lighter materials were developed to add endurance and improve performance. These developments ultimately went into longer-range systems such as

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51 US Congress, testimony before the Senate Armed Services Committee, March 1974, p. 3047.

52 George Heilmeier, Testimony, US Congress Senate Committee on Armed Services, March 17, 23, 29–31, 1977, p. 6241. As noted earlier, anti-jam capabilities and also image compression to reduce bandwidth are still key problems for achieving low-cost mini-UAVs.

53 Robert Fossum testimony, US Congress Senate Committee on Armed Services, Authorization of Appropriations for FY 79, Part 8: R&D, February 28, March 7, 9, 14, 16, 21, 1978, p. 6124.

54 David R. Heebner, Deputy Director, Defense Research and Engineering (Tactical Warfare Programs) US Congress, Testimony before the Senate Armed Services Committee, Part 6, April 1974, p. 3045.

the Amber development program that involved the "utilization of advanced composite structures …and sail-plane-like aerodynamics."[55] These materials then went into subsequent aircraft, including the Pegasus air vehicle built by Northrop Grumman for a joint DARPA/Navy contract, with stealth features, shaped like a kite and built largely with composite materials.[56]

Propulsion

The propulsion efforts included schemes for improved combustion systems for conventional engines, including an effort in the Amber development program to develop "an advanced lightweight, low-fuel-flow engine.[57] Other propulsion efforts included microwave propulsion from the ground for extended endurance tested by Raytheon in a DARPA-sponsored program, as well as solar propulsion for extended endurance.

Operational Concepts

DARPA was involved in a number of efforts to develop ways to use RPVs. In testimony in 1974, Deputy DDR&E Robert Heeber stated, "DARPA has led the way in conceptualizing applications for especially the smaller scale RPV and has led in a creative way to think in that area."[58] In another part of that testimony, Heeber indicated that the Agency may have been most successful in defining the missions for high-altitude, long-endurance RPVs.[59]

Sustainment

The Drone Control and Retrieval System (DCRS) was in development by DARPA in FY 1975. Preliminary design efforts occurred earlier. Participating contractors included Hughes Aircraft Company, RCA and Sperry Univac.[60]

Summarizing DARPA's Early RPV/UAV Work

DARPA was involved relatively early in the DoD's RPV work. It assisted the Navy and Marines with Dash and Snoopy. Its efforts in sensors were particularly noteworthy. This work

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55 Robert Duncan, DARPA Director, testimony, US Congress House of Representatives, Appropriations Committee, Part 5, 1987, p. 249.

56 *Journal of Aerospace and Defense Industry News*, February 27, 2001.

57 Robert Duncan testimony.

58 Robert Heeber, Testimony, US Congress, testimony before the Senate Armed Services Committee, March 1974, p. 3036.

59 Ibid., p. 3039.

60 Ibid.

focused on miniaturization of devices and improved communications. Between 1972 and 1977, the DARPA outlay for Mini-RPV research was nearly $15 million.[61] The efforts conducted through the 1970s laid the foundation for many of the later US RPV/UAV developments. But, with the transfer of programs to the Services in the late 1970s, DARPA was left temporarily out of direct involvement with the Services in RPV/UAVs. However, work continued on enabling technologies (especially sensor and command and control research) along with highly classified work with non-DoD Agencies (e.g., CIA) and the Air Force. For several years, there were no major cooperative open RPV/UAV system development activities with the Services.

SECOND GENERATION EFFORTS

After transferring its mini-RPV programs to the Services, DARPA undertook no major tactical UAV system developments for several years. DARPA did, however, continue to develop UAV application concepts. The Agency also worked on enabling technologies such as miniature sensors, anti-jam data links, the ICNS, and classified technologies for Intelligence agencies.

From 1980 to 1982, the DARPA TEAL RAIN program investigated advanced concepts for High Altitude Long Endurance (HALE) UAVs to perform reconnaissance, surveillance, and target acquisition missions. The objective was to find ways to keep UAVs aloft for days, even weeks. TEAL RAIN investigated nuclear-, solar-, and microwave-powered motors, as well as exotic materials and designs. These were unfettered, technology-push studies seeking to generate new ideas.[62] This program successfully demonstrated very long-endurance and high-altitude operation but failed to receive support to move into acquisition.

The Services were engaged in a number of individual programs designed to meet perceived requirements. While there were significant R&D efforts, there was little progress toward deployment of operational systems.

By the late eighties the Congress had grown concerned about some of the system failures, possible redundancies and the overall direction of UAV development within the DoD. The Conference Report for the Department of Defense Authorization Act of FY 1987 contained a request that the DoD submit a UAV Master Plan, with the FY 1988 budget request. The House Armed Services Committee further recommended that the Assistant Secretary of Defense for Command, Control, Communications, and Intelligence merge the programs of the Services for all

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61 Reed et al., *DARPA Technical Accomplishments,* p. 28-13.

62 Interview, Dr. Charles Heber, February 27, 2002.

classes of UAVs.[63] The principal problem was a common one for new technology in the DoD—the technology was not getting deployed into the system at a reasonable rate. Difficulties continued and Congress remained unhappy. The FY 1988 Defense Appropriations Act consolidated all non-lethal UAV developments into a single Joint Program Office in OSD—including DARPA's UAV funding.

Aquila

The Army's Aquila Program had one of the most difficult RPV development profiles of those studied and is almost universally used as an example of what not to do in a UAV acquisition program. It was one of the Army's first major UAV acquisition efforts. The program was initiated in 1979 from technology developed jointly with DARPA. The estimated cost was $123 million for a 43-month development effort. This was to be followed by a $440 million procurement of 780 air vehicles and associated equipment.[64] By the time the Army abandoned the program in 1987 because of cost, schedule, and technical difficulties, Aquila had cost over $1 billion, and future procurement costs were expected to have been an additional $1.1 billion for 376 aircraft.[65]

The original mission and design for Aquila was relatively simple. It was to be a small, propeller-driven aircraft (in the fashion of the earlier John Foster model airplane idea) that was portable by four soldiers and could provide ground commanders with real-time battlefield information about enemy forces located beyond the line of sight of ground observers.[66] However, as the development progressed, more missions and requirements evolved and considerable confusion developed over the specific deployment of the Aquila and what branch within the Army ought to own the capability: Should it belong to the artillery for deep targeting, intelligence for general intelligence gathering, or field commanders (divisions or Corps) for intelligence and operational planning?[67] Ultimately, the lack of cooperation among the US Army branches (artillery, intelligence, field commanders and others) and the inability to decide on the mission did considerable harm to the Aquila program.[68] Without clear ownership and a defined

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63 US General Accounting Office, *Unmanned Vehicles: Assessment of DoD's Unmanned Aerial Vehicle Master Plan*, NSIAD-89-41BR, Washington, DC: Government Printing Office, 1989.

64 US General Accounting Office (GAO), *Unmanned Aerial Vehicles: DOD's Acquisition Efforts,* GAO/T-NSIAD-97-138, April 9, 1997, p. 2.1.

65 Ibid.

66 Ibid.

67 William D. Knox, *Of Gladiators and Spectators: Aquila, A Case for Army Acquisition Reform*, USAWC Military Studies Program paper (Carlisle Barracks, PA: US Army War College, June 1994).

68 Interview with General Louis Wagner, US Army (Ret.).

mission, more requirements were placed on the vehicles and there was no real advocate for the system. According to GAO testimony, by the time the development program neared completion, it had grown to such a degree that many of the requirements for the small aircraft size conflicted with the many avionics and payload-related items the Army wanted to put inside the UAV.[69] For example, according to the GAO:

> Aquila was expected to fly by autopilot, carry sensors to locate and identify enemy point targets in day or night, use a laser to designate the targets for the Cooperhead artillery projectile, provide conventional artillery adjustment, and survive against Soviet air defenses. Achieving the latter expectation required development of a jam-resistant, secure communications link, but using the secure link degraded the video quality, which interfered with the ability to do targeting. During operational testing in 1987, Aquila was only able to successfully meet mission requirements on 7 of 105 flights.[70]

The GAO concluded, "The Aquila UAV acquisition effort in particular showed that a system that was intended to provide ground commanders with a simple reconnaissance capability, that is, to see over the next hill, was at least partly undermined by additional requirements, such as capability for precision targeting."[71]

These observations were supported by those of General Louis Wagner, who was the Army Deputy Chief of Staff for Research, Development and Acquisition, during a part of this period. In his view, disputes among the technical committee members and management group members regarding the UAV operational requirements had had a negative impact, particularly since they had not been resolved.[72] The disputes addressed such questions as: Should a UAV be able to fly 30 miles or 100 miles? Is it to be substantially used for field commanders at low level or for theater commanders?

Another major problem General Wagner noted was an inability to accurately estimate production costs. Several former participants mentioned this cost-estimating problem. It appears to be partly a function of an inability to focus on a number of systems to procure and to stick to that number. As the procurement numbers fell, unit costs increased. General Wagner reported that DARPA's UAV development activities were particularly important in critical components of UAVs such as sensors, navigation systems, and propulsion. But the Agency's success depended

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69 GAO/T-NSIAD-97-138, p. 2.1.

70 Ibid.

71 Ibid., p. 3.0.

72 General Wagner interview.

very much on the ability of the DARPA PM involved and the individual PM's ability to develop the required "connections" with other DOD organizations and contractors.[73]

Amber

Amber was arguably the most important UAV development program of the period. It involved many technology innovations and was the first of a new breed of endurance UAVs. DARPA initiated the program in 1984. However, the Amber concept can traced back to 1978, when a small firm, Leading Systems Incorporated, headed by innovative UAV developer Abraham Karem, approached DARPA with ideas for developing a long-endurance UAV. DARPA Director Robert Fossum funded a series of studies to demonstrate the feasibility of the suggested technologies, and he became an advocate for the concept.[74] Subsequently, DARPA funded Amber with the aim of creating a long-endurance, low observable UAV with sophisticated sensors for photographic reconnaissance and electronic intelligence missions. With the support of Navy Secretary Lehman, a strong backer of UAVs, the Navy joined the program after initial flight demonstrations.

The Amber program ran from 1984 to 1990. The Amber aircraft was 15 feet long, with a wingspan of 28 feet. It weighed 740 pounds and was powered by a four-cylinder, liquid-cooled piston engine. It had an inverted-vee tail, which protected the propeller during takeoff and landing. The airframe was made of plastic and composite materials, mostly Kevlar. Amber I first flew in October 1989. Seven Amber I systems were built and were used in evaluations through 1990. Amber had a reported flight endurance of more than 38 hours. It advanced earlier DARPA developments in materials, computers, communications, and sensors. Despite these developments the Amber program was canceled in 1990.

Amber had a flight endurance of 38 hours or more. The Amber program ran from 1984 to 1990, when it was canceled.[75]

Amber is an excellent example of the problems as well as the progress of UAVs of the period. While outstanding technology was developed over the course of the program, it did not meet Service desires. It was in the words one observer, "too good," i.e., it exceeded what the Services wanted. Moreover, it required operational approaches (launch from prepared sites by

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73 Ibid.

74 Interview with Robert Fossum, February 7, 2002. Fossum recalls he walked into a meeting in a DARPA Program Manager's office during which the concept of a high-altitude, long-endurance UAV was being presented. The PM was uninterested, but Fossum decided the idea should be pursued and began the project himself with funds he controlled.

75 Congressional Budget Office, *Options for Enhancing DoD UAV Programs,* p. 3.

well-trained technicians) that Services were not prepared to pursue. The Services acknowledged the outstanding technology, but saw it as inappropriate to their needs and operational schemes which they thought DARPA did not fully appreciate. The composite, retractable legs were considered too fragile for the unprepared sites from which the vehicle would have to operate, and the wing design was such that debris ("a fingerprint") would affect stability.

The Program was caught in the middle of the Congressional concerns over the failure of the Services to deploy UAVs and about the direction of UAV development in general. Amber was swept up into the consolidation of all nonlethal UAV developments into a Joint Program Office (JPO) in the Office of Secretary of Defense, which transferred all UAV research, development, test and evaluation from the Services and DARPA to the JPO.

Through the JPO, the Services determined that Amber was not appropriate for their operational concepts. Both the Army and the Navy argued that short-range UAVs were their first priority, and they supported the development of the Hunter and Outrider UAVs instead. At the same time, a fundamental disagreement appears to have arisen between DARPA and the Amber developer on the one hand, and the Navy program manager on the other. The Service participants were looking for a physically robust forward deployable system, while Amber had been conceived as a system that would be operated from prepared landing sites behind the combat zone. This was because it was a large system relative to mini-UAVs such as Aquila; therefore, it required prepared airfields and trained, technically proficient operators.[76] Moreover, the developer viewed himself as having to push the technology over the opposition of (from his perspective) less informed government participants. DARPA participants vouched that the technology was excellent as conceived and viewed the problem as arising from a Service inability to incorporate the technology into new operational modes that would make use of it. In Service participants' views, there was difficulty controlling the contractor's use of technology and money in what they tended to view as a continuing science project.

The end result was an impasse between DARPA, seeking to push the state of the art, and the Navy, seeking to develop a working system that fit its existing operational concept. Funding for Amber was cut, and then the program was terminated. LSI went out of business and sold the technology (including its export version, the Gnat-750) to Hughes, which in turn sold it to General Atomics, where it ultimately evolved into the Predator. Meanwhile, Hunter suffered three test flight crashes, which led to the cancellation of the program. The Outrider became

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76 The size of the system was driven by the objectives of long-endurance and high-altitude flight and by the need to accommodate sensor payloads that could not be fit on a smaller airframe. This combination of performance characteristics were seen by DARPA as key differences in objectives of their new HALE program and the earlier mini-UAV programs of the 1970s.

bogged down in increasing requirements from the Army and the Navy, resulting in an expensive system that did not perform any particular mission well.[77]

Condor

During this same timeframe Boeing developed the Condor, another long-range UAV. Boeing reportedly initially developed Condor with corporate funds, but there also was support from non-DoD sources. As part of its TEAL RAIN, DARPA supported the flight-testing of the Condor in a military configuration. The first aircraft rolled out in 1986. It was considered a "significant milestone in the development of endurance UAVs. The Condor featured lightweight all-composite and honeycomb structures, autonomous controls, high altitude aerodynamics, and a fuel-economical propulsion system."[78] The UAV was large enough (it had a 200-foot wingspan) to carry a big payload and during test flights it carried about 1,800 pounds of instruments. It was powered by two, six-cylinder liquid-cooled piston engines. The engines had two-stage turbocharging for high altitude operation and a gearbox that shifted the propellers to higher RPM at these high altitudes.[79] It was capable of operating autonomously from takeoff to landing, using a flight control program, but communications links allowed a mission to be modified in flight. The Condor reached a record altitude of 67,028 feet in a 1988 flight. This altitude record for propeller-driven aircraft was unsurpassed until June 1997, when NASA's Pathfinder UAV reached a record altitude of 67,350. The Condor was not inexpensive. It was estimated to cost about $20 million without payload. However, it had a range of 9,000 miles and 2.5 days' endurance. Because of these capabilities it was viewed as a "cheap satellite" for many applications.

Condor is viewed as a positive example of DARPA's collaboration with commercial firms. The collaboration between Boeing and DARPA resulted in a very advanced system to meet an identified Navy need to counter Soviet Backfire bombers.[80] The Navy had stated a requirement for 50 units. However, the development fell victim to changing Service demands when the DoD transferred the Navy mission for which the Condor had been designed to the Air Force.[81] The Navy canceled its support for the Program and the Air Force did not pick it up.

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77 <http://www.vectorsite.net/twuav6.html#m4>.

78 Greg Goebel, "Condor and Amber," *Unmanned Air Vehicles*, <http://www.vectorsite.net/twuava.html#m2>.

79 Ibid.

80 Interview with Mr. Charles Heber. Also see Thomas Erhard, *Unmanned Aerial Vehicles in the United States Armed Services: A Comparative Study of Weapons System Innovation*, Dissertation, Baltimore, MD: Johns Hopkins University, 2001, Chapter 4.

81 Ibid.

Although Boeing reportedly spent more than $100 million of its own funds on the development of the Condor, it ultimately had no buyer and the aircraft was mothballed. The Condor is viewed as the conceptual prototype of the Global Hawk.

Pioneer

The Pioneer UAV system, purchased as a nondevelopmental item from Israel and then reengineered during this period, has some DARPA technical antecedents combined with a good deal of Israeli technology developments and operational experience. United States military operations in Grenada, Lebanon, and Libya convinced then Secretary of the Navy Lehman that there was a need "for an on-call, inexpensive, unmanned, over-the-horizon targeting, reconnaissance, and battle damage assessment (BDA) capability for local commanders."[82] As a result, in July 1985, the Secretary directed the expeditious acquisition of unmanned aerial vehicle systems for fleet operations using nondevelopmental technology. The Pioneer won the competitive fly-off and two Pioneer systems were procured in December 1985 for an accelerated testing program to be conducted during 1986. The initial system delivery was made in July 1986 and subsequently deployed on board the battleship USS Iowa in December 1986. During 1987, three additional systems were delivered to the USMC where they were operationally deployed on board LHA class vessels as well as with several land based units. The system became a joint service program in 1990 when the US Army fielded its own Pioneer system.[83]

The Pioneer is 14 feet long and powered by a 26 horsepower, rear-mounted engine. The aircraft weighs almost 500 pounds. It began to encounter unanticipated problems almost immediately after the Navy deployed it. Difficulties in recoveries aboard ship and electromagnetic interference from other ship systems were two serious problems that led to a significant number of crashes.[84] The system also suffered from other shortcomings. One of these was engine failure. Crashes led to the temporary termination of Pioneer operations pending engine modifications and a change in the type of fuel used. A fuel change to aviation gasoline fixed the engine failure problem but forced the Navy to start a development program for a new Pioneer engine that would use a less volatile fuel considered acceptable for shipboard operations.[85] Ultimately, the Navy conducted a $50 million research and development effort to

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82 Steven E. Reid, *Operational use of the Pioneer Unmanned Aerial Vehicle (UAV) system*, paper presented at the SPIE Technical Conference *Airborne Reconnaissance XX*, Denver, Colorado, on August 6, 1996.

83 History of Pioneer, <http://www.aaicorp.com/>.

84 GAO/NSIA90-234, Unmanned Aerial Vehicles, Appendix I, p. 10.

85 Ibid.

bring the nine Pioneer systems up to a level it described as a "minimum essential capability."[86] DARPA was very involved in upgrading the system but reportedly did not collaborate with Israelis on it (there was limited unofficial exchange of technical information among US and Israeli technical personnel).[87]

Beginning in 1990, the air vehicle's structural components were modified to incorporate reliability and maintainability improvements and a streamlined fuselage design. As a result of these and other changes, the mission endurance now exceeds 6 hours. The current Pioneer is equipped with autopilot navigation and communication equipment that allow it to operate in either preprogrammed or manual control modes.

Although the Pioneer reportedly "never met objective requirements, in its first 10 years of service" it supported every major US contingency operation during the period including the Gulf War and operations over Bosnia, Haiti, and Somalia.[88] It is credited with supplying valuable information and targeting data. It supports the argument that deploying a less-than-perfect system is better than deploying no system.

Gnat-750

The Gnat-750 was developed as the export version of Amber and shares many of the structural characteristics of that vehicle.[89] The Gnat-750 and its upgrades are slightly longer than the Amber, and its wingspan at 35 to 42 feet is significantly longer that the 28-foot Amber. However, the reported endurance of 30 to 42 hours is about the same as that of Amber. The Gnat-750 has both electro-optic and infrared sensors, and the upgraded systems have television relay capability. The vehicle must be launched and recovered from a prepared landing strip at least 2,200 feet long.

When the funding for the Amber program was lost, the technology owned by Leading Systems for Amber and the export version (Gnat-750) was sold to Hughes and then subsequently sold to General Atomics. Along with the technology went Abraham Karem, Amber's developer, who subsequently worked with both Hughes and General Atomics as a consultant.[90] Eight of the Gnat-750s were reportedly being developed by Leading Systems at the time of the transfer.[91]

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86 <http://www.fas.org/irp/program/collect/pioneer.htm>.

87 Interview with Bradford Brown.

88 <http://www.fas.org/irp/program/collect/pioneer.htm>.

89 <http://www.uavforum.com/vehicles/production/gnat750.htm>.

90 Interview with Abraham Karem.

91 Greg Goebel, "Condor and Amber."

These developments ultimately led to sales to Turkey and to the CIA. The Amber program had included CIA involvement and when the aircraft was rejected by the Services as being inappropriate for their field needs, the CIA continued as a customer. The Gnat-750 was then further developed for the Central Intelligence Agency.[92] The vehicle was employed by that Agency in the former Yugoslavia in 1994.

The Gnat-750 has been the basis for a number of other UAVs, including the Altus, the Predator, Gnat-750 XP (eXtra Performance), and I-Gnat (Improved) models.

Congress and DoD Program Management Consolidation

As already noted, Congress had shown increasing concerns over UAV developments in the 1980s. Finally, legislation passed in FY 1988 directed the consolidation of the DoD's nonlethal UAV program management with the aim of reducing redundant UAV programs and providing an integrated management structure.[93] The resulting UAV Joint Project Office (UAV JPO) appears to have continued to suffer from disputes among the Services and Agencies over UAV operational requirements and ownership,[94] but it reportedly embarked upon a four-element UAV program in response to approved Mission Need Statements. The UAV JPO supported four core UAV programs: close-range (CR), short-range (SR), medium-range (MR) and endurance. The core medium-range UAV was canceled in October 1993 and the remaining programs were reorganized into two groups: the Joint Tactical Program (absorbing the CR and SR) and the Endurance Program.[95]

Among the requirements established during this period was one approved by the Joint Requirements Oversight Council (JROC) in 1990 to establish a Long Endurance Reconnaissance, Surveillance, and Target Acquisition (RSTA) Capability:

> The intent was to provide warfighting commanders in chief (CINCs) with the capability to conduct wide-area, near-real-time RSTA, command and control, SIGINT, electronic warfare, and special-operations missions during peacetime and all levels of war. The CINCs would be able to exercise this capability against defended and denied areas over extended periods of time.[96]

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92 <http://www.vectorsite.net/twuava.html#m2>.

93 RAND Corporation, *Innovative Management in the DARPA HAE UAV Program*, MR-1054-DARPA, 1999, Santa Monica, CA: RAND Corporation, p. xiv.

94 Bradford Brown interview.

95 RAND, *Innovative Management in the DARPA HAE UAV Program.*

96 Ibid., p. 6.

In July 1993 the JROC endorsed a three-tier approach to acquiring an "endurance" capability. The approach was defined as follows:

- Tier I: Quick Reaction Capability
- Tier II: Medium Altitude Endurance
- Tier III: "Full Satisfaction" of the Mission Needs Statement

Tier I and Tier II were implemented as the Gnat-750 (Tier I) and Predator (Tier II). A Tier III system was not identified. At the time there was a classified developmental system that might fulfill the Tier III requirements, but it was considered expensive.[97] The results of DoD's efforts to provide this capability are discussed below under Third Generation UAVs.

Summarizing Second Generation UAV Activities

The ability to fully assess DARPA's UAV role in this period is limited because some of DARPA's UAV activities were highly classified, and remain so. Technological developments from these activities spilled over into the less classified UAV projects. *That being said, it is clear that DARPA did develop some important UAV technologies during the decade of the 1980s.* DARPA did not drop totally out of UAV development when it passed vehicles over to the Services for further development and deployment in the late 1970s. It remained involved in a number of activities. This appears particularly true in the case of enabling technologies such as guidance, computers, communications and data linkages, structural materials and propulsion. It experimented in many novel ideas. A good example is propulsion where work on solar flight, microwave propulsion, and novel ideas in conventional aircraft engines were examined. These were important, if not for immediate use in Service UAVs, then for the future. DARPA was also involved in the development and testing of air vehicles, such as Amber and its derivative the Gnat-750; in testing a military Condor; and in the redesign of the Pioneer. DARPA also supported conceptual studies of how to employ UAVs. Such studies were critical to developing technology for the future.

However, for all the positive technological developments of the period, the great failing was the inability to deploy those technologies in the Services to support forces in the field. In a variation on a theme seen earlier in the Assault Breaker project and the stealthy ship, introducing the RPV/UAV technology into the field continued to frustrate advocates. The explanations for the failure are numerous and sometimes conflicting—depending upon the position of the person making the statement. These observations are grouped and summarized below.

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97 OSD Working Paper, *HAE UAV Chronology*, p. 1.

Operations

- Although there was general agreement that RPVs/UAVs were good for intelligence gathering, targeting, and general observation, there was no common understanding of how these vehicles might be used. This lack of common understanding led to disputes over what Service (Navy, Air Force, or possibly CIA in the case of Amber) or Branch of Service (Artillery, Military Intelligence, or Field Commanders in the case of Aquila) should own the assets. These disputes resulted in lack of strong advocates for the systems' deployment and loss of funding when matched against other Service priorities. The disputes also resulted in "mission creep" as more and more gadgets were strapped on the air vehicles in hopes of performing multiple missions. In the case of Aquila this trend greatly contributed to the program failure as the multiple capabilities actually interfered with each other.
- The lack of agreement on operations also led to disputes over what technology ought to be developed. Service participants often sought forward deployment from unprepared locations. Other participants favored deployment and operation from prepared airstrips. These disputes and the resulting technology stymied deployment until operational concepts changed.
- The lack of agreement on operations also led to disagreement over the size of the future requirement. This lack of good understanding of force requirement had a negative impact on estimates of future unit costs. Moreover, missions changed over time and Services cut programs in response to these changes. The Condor, for example, was a victim of a mission shifting away from the Navy and to the Air Force.

Technology

- Technologies (components) tend to develop at different rates. Thus, if deployment hinges on having every element in place, deployment will be greatly delayed. The Pioneer was criticized for its need for modification, but it was praised for having provided a deployed (although flawed) capability.
- DARPA tended to push the technology further than the Service participants deemed necessary. The negative effects of this technology push were exacerbated by the inability of the Services to develop viable operational plans for UAV use.

Program Management

- There are differing opinions about DARPA's program management in the period. DARPA's role was important not only technically, but also because of its streamlined R&D acquisition capability. However, this acquisition approach was lost as the programs transitioned to the Services and into production and procurement.
- The outside view of DARPA program managers in this period was mixed. They were sometimes criticized for having too little contact with the Services and industry and

sometimes for having too much contact and oversight. It would be difficult to draw any conclusion on this on the evidence of the interview data.

- Congressional interference was raised as a problem in the period by several of the participants. This was particularly true with regard to stability of funding and long-term commitment to programs.
- On the broader management front, the establishment of the UAV Joint Project Office, while not fully solving the problems of operational requirement identification and coordination of development, appears to have at least focused the overall effort along coordinated operational lines (Quick Reaction, Medium Endurance, and Full Satisfaction of Need) that could provide the basis for technology development.

THIRD GENERATION EFFORTS

Following the Gulf War in 1991, a Defense Science Board (DSB) study highlighted serious deficiencies in airborne intelligence, surveillance and reconnaissance (ISR), particularly for wide-area coverage. The report concluded that there was a need for enduring loitering ISR capabilities and determined that a family of UAVs was needed.[98] The regional combatant commanders expressed a need for long-endurance surveillance for counterdrug and peacekeeping missions.[99] Previously, in 1990, the Joint Requirements Oversight Council (JROC) had set down a requirement to establish a long-endurance Reconnaissance, Surveillance, and Target Acquisition (RSTA) capability:

> The intent was to provide warfighting commanders in chief (CINCs) with the capability to conduct wide-area, near-real-time RSTA (reconnaissance, surveillance and target acquisition), command and control, SIGINT, electronic warfare, and special-operations missions during peacetime and all levels of war. The CINCs would be able to exercise this capability against defended and denied areas over extended periods of time.[100]

A 1993 DSB study on Global Surveillance, co-chaired by Robert Hermann and Larry Lynn, looked at the issues in greater detail and reinforced the need for endurance UAVs (and proposed the development of small radar satellites, which will be described in the next subsection). At the time, there were three endurance UAVs—known as Tier I, Tier II, and Tier III—in use or in development. Tier I was the Gnat 750 (derived from Amber), which provided a quick reaction capability; Tier II was a proposed program to scale up the Gnat-750 into a medium altitude endurance UAV, which would later became known as Predator; and

98 Interview with Charles Heber, February 26, 2002.

99 Interview Robert Williams, March 26, 2001.

100 Hundley, *Past Revolutions, Future Transformations*, p. 6.

Tier III was a classified technology development program for a stealthy, very long endurance capability. Top OSD and intelligence community leadership—Secretary of Defense William Perry, Under Secretary of Defense John Deutch, and James Woolsey, Director of the CIA—were concerned that the proposed approach for meeting the Tier III requirement was far too expensive. In mid-1993, they initiated an internal review of all airborne and satellite surveillance led by Larry Lynn, who had just rejoined the government as Deputy Under Secretary for Advanced Systems and Concepts. A 3-month study, drawing on the work of the DSB studies, concluded the following:

- There was a need for greater focus and leadership attention in airborne reconnaissance.
- The Tier II Program should be accelerated.
- The Tier III Program should be terminated and replaced with a U-2 like UAV with unit flyaway cost as a major requirement. (The study argued that this flyaway cost could be $10 million.)

In response, Perry, Deutch, and Woolsey, supported by Emmett Paige (Assistant Secretary of Defense for Command, Control, Communications and Intelligence) and General Mike Carns (Vice Chairman of the Joint Chiefs of Staff), directed the following:

- The formation of the Defense Airborne Reconnaissance Office (DARO), directed by General Kenneth Israel, reporting to Larry Lynn[101]
- The acceleration of Tier II
- The initiation of a "Tier II+" Program, replacing Tier III

Israel and Lynn were convinced that no DoD organization other than DARPA could sustain the focus on cost that would be required to succeed in the goals of Tier II+. They convinced DARPA Director Gary Denman to allow DARPA to manage the effort, with DARO providing most of the funding. DARPA was tasked to flesh out a system concept for the Tier II+ while maintaining an aggressive unit flyaway price goal of $10 million.[102]

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[101] The formation of DARO also responded to continuing congressional concerns about DoD's management of UAVs. DARO was a broader, more powerful office than the JPO. It had responsibilities for policy, budgeting, demonstration and acquisition of all manned reconnaissance systems, sensor development, ground station support, and UAVs.

[102] At the same time the Tier II+ goals were coming to light, Lockheed submitted an unsolicited proposal for development of what became known as the Tier III- UAV, a less capable (than the original Tier III) but still highly stealthy configuration capable of fulfilling the penetrating reconnaissance role. In 1994, OSD decided to proceed with both programs under DARPA direction. Dark Star, the Tier III- program, was developed in parallel with Global Hawk, the Tier II+ program, but encountered technical problems. With increasingly constrained budgets, the program was in favor of proceeding with just Global Hawk.

Two deployed UAVs, Predator and Global Hawk, resulted from these efforts. Predator, the Tier II system based on previous DARPA technologies,[103] was designed for near-real-time reconnaissance, surveillance, target acquisition, and battle damage assessment in all weather conditions.[104] It has a flight duration of more than 20 hours and a flight range of 926 kilometers. Its communications system includes a satellite link to relay images beyond line of sight of its ground control station.[105] Perhaps most importantly, Predator's first experimental flight was just 6 months after program initiation, thanks in part to the use of the then experimental Advanced Concept Technology Demonstration (ACTD) process. The ACTD process provided for streamlined management and oversight, early participation of the user community, and a tight schedule.[106] It also permitted advanced operational prototypes to be sent to CINCs for experimental use. As a result, Predators were deployed in Bosnia about a year later. They were subsequently used in Kosovo, in the No-Fly Zones in Iraq, and in Afghanistan, where it also was used as an armed UAV (with Hellfire missiles).

Global Hawk, the Tier II+ system (also based on previous DARPA technologies)[107] is a large aircraft designed to have 24-hour loiter time over the target area. The aircraft carries both an EO/IR sensor and a SAR with moving target indicator (MTI) capability, allowing day/night, all-weather reconnaissance. It can provide wide-area coverage (up to 40,000 square nautical miles per day) with low resolution, side-looking SAR images, or high resolution spot SAR images.[108] Sensor data is relayed over line-of-sight (X-band) and/or beyond-line-of-sight (Ku-band SATCOM) data links to its Mission Control Element (MCE).[109]

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[103] Predator can be traced all the way back to DARPA's work in Praeire. Israel purchased Praeire II technology, built on it, and used it effectively in combat. The technology and operational concepts came back to the US through Abraham Karem, President and lead designer at Leading Systems Incorporated (LSI). DARPA provided LSI a contract for $40 million in 1984 to build Amber. During the development, LSI also produced an Amber Lite for export, which was adapted by the CIA to become the Gnat-750. In bankruptcy, LSI sold Amber technology to Hughes, which in turn sold it to General Atomics, where it was incorporated into Predator.

[104] Congressional Budget Office, *Options for Enhancing DoD UAV Programs*, pp. 14–15.

[105] Ibid., p. 20.

[106] Then Deputy Secretary of Defense Perry coined the term "Advanced Concept Technology Demonstration," or ACTD, because the term "Advanced Technology Demonstration," or ATD, was already being used by the Services but did not seek to accomplish the same thing.

[107] Because Global Hawk is a classified program, its development history is harder to discern. It appears to go back to Boeing's development of Condor. DARPA funded flight testing for Condor, but the intended customer in the Navy would not buy it. DARPA's High Altitude Long Endurance (HALE) program developed technologies that were incorporated in classified CIA programs before emerging as Global Hawk.

[108] Office of the Secretary of Defense, *Unmanned Aerial Vehicles, Roadmap, 2000–2025*, US Department of Defense, April 2001, p. 4.

[109] Ibid.

On the Global Hawk program, DARPA pioneered several new acquisition methods to speed technology transition.[110] Like Predator, the program was designated an ACTD. It also used Section 845 Other Transaction Authority (OTA), which allowed DARPA to waive almost all traditional acquisition rules and regulations in favor of a tailored program structure with increased contractor design responsibility and management authority. Integrated Product Teams composed of contractor and government personnel worked together to resolve issues. The Global Hawk program had only one firm requirement: a unit flyaway price of $10 million for air vehicles 11–20 (in FY 1994 dollars). All other performance characteristics were stated as goals and could be traded to achieve the target price.[111]

Although the Global Hawk was still in an early acquisition phase, it was deployed in support of Operation Enduring Freedom in Afghanistan.[112] The method of deployment was unique in that nontraditional crewmembers, mostly from the test and evaluation community, were used as operators. A turning point in the transition from acquisition to deployment for both Global Hawk and Predator occurred when General Joseph Ralston, Commander of the Air Force Air Combat Command, formed an operational UAV squadron. This resulted in a cadre of Service operational and development personnel to take over the program from DARPA. The Air Force subsequently set up a UAV battle lab to explore operational concepts.[113]

While difficulties persist, Predator and Global Hawk signify the beginning of UAV acceptance as a vital element of the US force structure. Early on, DARPA recognized the warfighting potential of deploying sensing devices on small UAVs. It then fostered the development of various UAV systems and enabling technologies such as structures, propulsion, guidance, sensors, and communications. With top leadership and continued congressional support, the potential of UAVs is becoming a reality.

Predator

The Predator grew out of technology developed in the Gnat-750 and Amber programs to provide the Tier II medium-altitude and wave capability. An ACTD contract for the Predator was awarded to General Atomics in 1994, and the aircraft was transitioned to the Air Force in

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110 RAND, *Innovative Management in the DARPA HAE UAV Program*, p. xiv.

111 Charles E. Heber, Director, High Altitude Endurance Unmanned Air Vehicle Program Office, Defense Advanced Research Projects Agency, Prepared statement before the Senate Armed Services Committee and Subcommittee on Airland Forces, March 29, 1996. Unit costs reportedly have gone up to $15 million.

112 US General Accounting Office, *Unmanned Aerial Vehicles: Progress of the* Global Hawk *Advanced Concept Technology Demonstration*, Washington, DC: US Government Printing Office, April 25, 2000, p. 1.

113 Thomas G. Mahnken, “Transforming the US Armed Forces: Rhetoric or Reality,” *NWC Review*, Summer 2001.

August 1997.[114] It is a medium-altitude, medium-range UAV. Its normal operating altitude is 15,000 feet and it can function as high as 25,000 feet. Its normal operating (or "cruise") speed is about 120 kilometers per hour. The Predator has a stated endurance of more than 20 hours and a radius of 926 kilometers. Its communications system includes a satellite link, which allows it to operate beyond the line of sight of the ground control station and still relay images back to the user.[115] It has a gimbaled electro-optical/infrared (EO/IR) sensor, a synthetic aperture radar, and GPS/INS, giving it a day/night, all-weather (within aircraft limits) reconnaissance capability. It uses both a line-of-sight (C-band) and a beyond-line-of-sight (Ku-band SATCOM) data link to relay color video in real time to commanders."[116] It has also been deployed as an armed UAV. It has been used in Bosnia, Afghanistan, and Operation Iraqi Freedom.

The Predator owes much of its technology to DARPA developments. Its fielding was fostered by the decision to make use of the ACTD as a vehicle to facilitate moving the technology to the military user. According to Major General Kenneth Israel, the Director of the Defense Airborne Reconnaissance Office (DARO) in 1997:

> The Predator UAV program, as an ACTD, is an example of acquisition reform in action. The judicious use of creative modeling and simulation has directly contributed to managing costs in all aspects of the ACTD by predicting operational effectiveness in conjunction with abbreviated operational assessments, assessing air vehicle survivability cost-effectively, determining optimum system configuration, and assessing alternative force structure options.[117]

Global Hawk/DarkStar

For meeting the Tier II+/Tier III- capabilities for longer-term endurance, the Global Hawk and DarkStar were run as separate development programs but were managed together with a Joint Program Office (JPO) under a DARPA Program Director. The program was formally designated an ACTD in 1995, and subsequently a formal MOU with OSD and the three Services was signed in August 1995. The JPO had Air Force and Navy presence from the start (1994) with Army presence starting in 1996. There was a plan to transition the program to the Services and an Air Force System Program Office (SPO) was established in early FY 1996. Following the

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114 <http://www.uav.com/home/index.html>.

115 Congressional Budget Office, *Options for Enhancing the DoD's UAV Programs*, p. 20.

116 Office of the Secretary of Defense, *Unmanned Aerial Vehicles, Roadmap, 2000–2025*, Section 2, Department of Defense, April 2001, p. 30.

117 Major General Kenneth Israel, Director, Defense Airborne Reconnaissance Office, *Modeling and Simulation Employed in the Predator Unmanned Aerial Vehicle Program*. Downloaded from <http://www.fas.org/irp/agency/daro/product/predms.htm>.

signing of the MOU, a formal Oversight Committee chaired by the Deputy Under Secretary for Acquisition and Technology was established. The Committee "met, at a minimum, once every 6 months and was involved in all major decisions impacting the program direction."[118] In addition there were a total of six Integrated Product Teams supporting the program. These were placed under an Air Force established Overarching IPT in late FY 1996. Transition to the Air Force occurred in late 1998.

The Program as originally structured had three main elements: Global Hawk, which was to be a 'highly capable, moderately survivable' UAV; DarkStar, which was expected to be a 'moderately capable, highly survivable' UAV; and a Common Ground Segment to provide launch, recovery, and mission control elements.[119] The Global Hawk vehicle is a large aircraft designed for high-altitude, long-endurance operation. It can provide wide-area coverage (up to 40,000 square nautical miles per day). It takes off and lands conventionally on a runway and carries a 1,950-pound payload for up to 36 hours. The aircraft carries both an EO/IR sensor and a SAR with MTI capability, allowing day/night, all-weather reconnaissance. Sensor data is relayed over line-of-sight (X-band) and/or beyond-line-of-sight (Ku-band SATCOM) data links to its Mission Control Element. The MCE can distribute imagery to up to seven theater exploitation systems.[120]

The DarkStar aircraft was a smaller aircraft with less range and endurance than the Global Hawk. It carried the same basic sensor packages as the Global Hawk and incorporated low observable design and technologies to make it more survivable in high threat areas. Although it had less bandwidth, it could communicate effectively with the same ground station and would have had similar radar and sensor capabilities.[121] Figure VI-1 shows how the system was expected to operate.[122]

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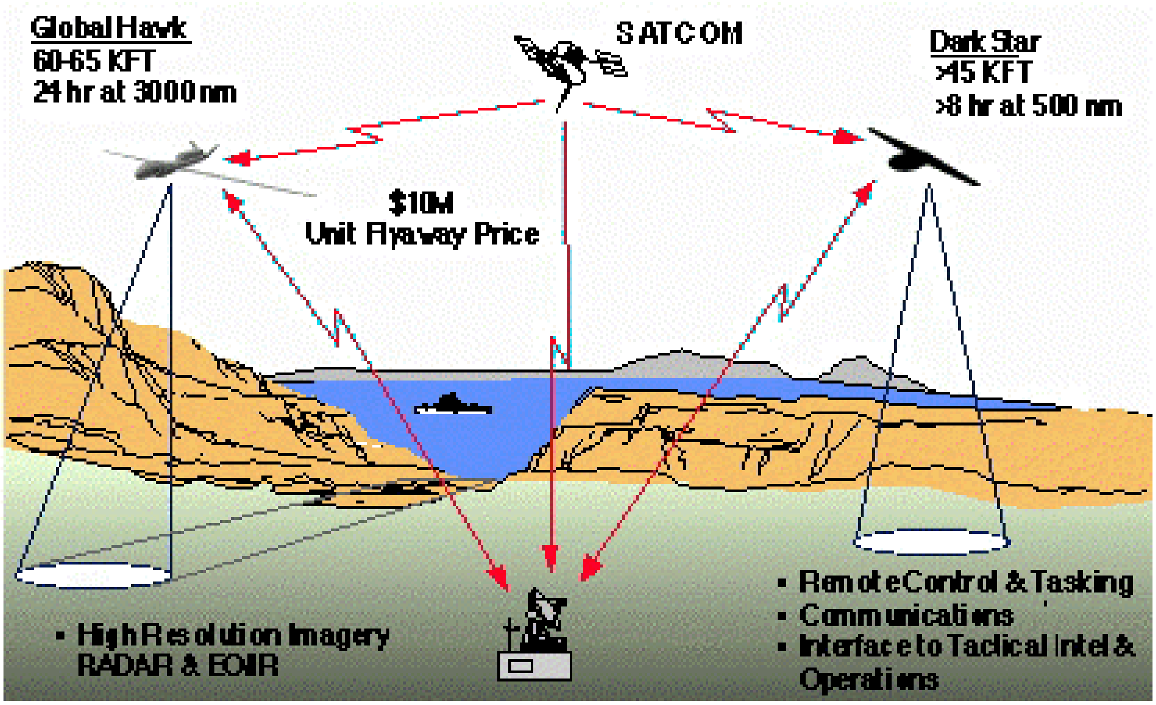
118 OSD Working Paper, *HAE UAV Chronology.*

119 US General Accounting Office, *Unmanned Aerial Vehicles: Progress of the Global Hawk ACTD*.

120 Office of the Secretary of Defense, *Unmanned Aerial Vehicles, Roadmap, 2000–2025.*

121 *Unmanned Aerial Vehicles: Progress of the* Global Hawk *ACTD.*

122 "RQ-3A DarkStar Tier III Minus," Federation of American Scientists, Intelligence Resource Program.



Source: FAS Intelligence Resource Program. RQ1-A Global Hawk (Tier II + HAE UAV downloaded from <http://www.fas.org/irp/program/collect/global_hawk.htm> 9/6/01.

Figure VI-1. High Altitude Endurance Unmanned Aerial Vehicle

The design and development programs for both the UAVs were conducted based on a philosophy that cost is an independent variable. Cost was important—indeed the DoD told Congress that it was the only firm requirement:

> The contractors are being driven to a $10 million UFP requirement, and all other system attributes, including performance, are traded off against this requirement…[T]he intent is to arrive at a system solution which is not the best we can imagine but rather good enough to do the job."[123]

Technical problems, however, affected both cost and schedule in the program and caused fundamental changes to be made in the program structure. Software development and redundancy issues with DarkStar ultimately led to the crash of vehicle #1 on its second fully autonomous flight and caused a 2-year delay in the program. Software development and payload development problems with Global Hawk resulted in a program delay of over a year. These program delays translated into increases in cost of development. These problems resulted in major changes in the program in April 1997 that limited the total program assets to 5 Global

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[123] Heber, statement before the Senate Armed Services Committee and Subcommittee on Airland Forces, March 29, 1996.

Hawk*s*, 4 DarkStars (including the one that crashed), and 2.5 Common Ground Segments. Additionally, the demo program was reduced from the original 24-month period to 15 (and later 12) months.

All of this was done to accommodate a position by the USD(AT) that no further funds were available to increase the program bottom line. This change in program content had a significant effect on UAV unit flyaway price. These were estimated to have risen to about $14 million.[124] The GAO subsequently estimated the unit flyaway price for the Global Hawk was averaging $15.3 million in 1994 dollars and might climb even higher before the program reached its completion as this number assumed no additional changes to the aircraft and higher annual production rates than the DoD planned.[125] Budget constraints resulted in the DoD choosing Global Hawk's range and endurance over DarkStar's stealth, and DarkStar was terminated in 1999.[126] Global Hawk continues as an Air Force Program.

Micro Air Vehicles

The DoD is also involved in a number of projects aimed at developing micro-UAVs. These vehicles are quite small (some insect size) and aim to provide capabilities to the forward maneuver units. DARPA's Tactical Technology Office is the lead on the Micro Air Vehicles (MAV) Program. The MAV Program:

> …will develop the technologies needed for an air vehicle system that shall be very small (threshold less than 1 foot, goal about 6 inches) and capable of autonomous operation as part of a military force. The MAV shall be capable of conducting military operations any time of the day or night, in all weather conditions under tactical conditions that include dust created by movement of neighboring vehicles and use of smoke obscurants by friendly and enemy forces. The MAV shall be capable of operating on the battlefield with "maneuver forces," including armored vehicles and performing operations of up to one-hour duration without requiring re-supply or significant intervention by operators or support personnel. The MAV system shall be designed and developed to conduct "close in" reconnaissance to allow the small unit leader to know literally what is over the next hill or around the next corner.[127]

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124 OSD Working Paper, *HAE UAV Chronology.*

125 US General Accounting Office, *Unmanned Aerial Vehicles: Progress of the* Global Hawk *ACTD,* p. 1.

126 RQ-3A DarkStar Tier III Minus.

127 Office of the Secretary of Defense, *Unmanned Aerial Vehicles*, *Roadmap, 2000–2025*, p. A-34.

Summary of Third Generation and DARPA UAV Activities

By the late 1990s, UAVs were beginning to be fielded in such numbers that they were having a significant impact on the battlefield. Previously, they had simply been a curiosity, but by the late nineties they had become increasingly capable, providing the near or real-time intelligence in considerable depth. Some of these aircraft were armed so that they could not only find and target for others, but could also attack the target themselves.

Today, while some failures and program terminations continue to occur, particularly among short-range tactical systems, UAV developments are increasingly successful, and as a consequence their deployment should increase substantially in the future. A major part of this positive cycle appears to be an increased willingness on the part of those in the field to accept some initial compromises in operational strategy and to accept shortcomings in the vehicles and work around them. This appears to have been stimulated by the use of the DoD's UAV ACTD acquisition strategy. The acquisition strategy was particularly important in the case of the Global Hawk and DarkStar Programs, which were viewed "as much an experiment in acquisition as it was a prototype system development."[128] DARPA played an important part in this acquisition strategy. It had the capability to use its Section 845 capability to streamline the acquisition process and to make greater use of commercial components and processes. The Services now also have the Section 845 capability, although they do not appear to be using it a great deal for UVA R&D.

However, while there were increasing UAV successes during the period, and the Services appeared to be more oriented toward UAV deployment than in the past, development challenges still continue to plague efforts especially for the short-range systems. The problems seem to be attributable to the following: 1) the technological difficulties associated with the development programs, 2) lack of a clear understanding of how to use the proposed systems and therefore lack of agreement on requirements, 3) changing Service demands in both technology and numbers of systems, and 4) lack of clear ownership within the military and therefore lack of support for the system. Moreover, these systems continue to compete with other Service priorities and make it difficult to gain "buy-in" from important elements of the Services. A report by the Congressional Budget Office summed up some of these problems, noting that the tendency has been for the Services to demand increasing capabilities that are then integrated into the developing platforms. This additional capability increases the technological challenges of integrating the subsystems as well as increasing the weight of the vehicle and quickly outstripping the capacity of the platform

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[128] OSD Working Paper, *HAE UAV Chronology.*

to accommodate subsystems. These problems have reportedly tended to lead to cost overruns, failed tests, and limited capabilities of the early UAVs.[129] The ACTD process has helped cut through some of this (if properly run) by allowing users to see what might be available at a given capability level. Making system cost a primary constraining requirement, as in the case of Global Hawk and DarkStar, appears to have some utility. While the Global Hawk did not hit its cost goals, it is being employed as a fielder system.

A Rand Corporation study of acquisition issues examined the HAE UAV Program for DARPA. In an initial report Rand concluded "the HAE UAV program was structured to address problems that had plagued past UAV development efforts. The program's innovative acquisition strategy featured several key elements:"[130]

- The program was designated as an Advanced Concept Technology Demonstration. This allowed use of a streamlined management and oversight process, provided for early participation of the user community, and bound the schedule length. The goal of the ACTD was to demonstrate military utility in a relatively short timeframe. The use of mature technology was intended to limit risk.
- Section 845 Other Transaction Authority (OTA) allowed DARPA to waive almost all traditional acquisition rules and regulations. The result was a tailored program structure with increased contractor design responsibility and management authority.
- Integrated Product and Process Development (IPPD) used Integrated Product Teams (IPTs) to manage the program. Each IPT included contractor and government personnel who worked together to resolve issues.
- Cost was the single firm requirement. The HAE UAV program had only one requirement: a unit flyaway price (UFP) of $10 million for air vehicles 11–20 (in FY 1994 dollars). All other performance characteristics were stated as goals and could be traded to achieve the UFP target.

This combination of acquisition innovations appears to have been unique to the HAE UAV program in this period. While other programs included ACTD or IPPD experience, the HAE UAV was the first program to combine all of these elements into an acquisition strategy.

The Predator program achieved atypical success levels in the period. This has been attributed in several sources to the fact that it was based on the Gnat-750, which was already

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[129] See for example: GAO, *Unmanned Aerial Vehicles: DoD's Acquisition Efforts;* and GAO, *Unmanned Aerial Vehicles: Progress of the* Global Hawk ACTD.

[130] Rand Corporation, *Innovative Management in the DARPA HAE UAV Program*, p. xiv.

technologically mature.[131] The Predator ACTD required the CIA's Gnat to prove itself as a mature technology before the DoD would commit to acquiring the system. The Predator prototypes were deployed in Bosnia in 1995 and 1996 as part of the ACTD demonstration process.[132] In contrast, other programs such as the DarkStar and Global Hawk were new systems that posed additional engineering and development challenges.

A recent GAO report declared that the ACTD approach has improved the DoD's UAV programs. The GAO claimed that the approach helped the Predator to achieve technological maturity at a rapid pace. It also argued that the ACTD both allowed the DoD to cancel the DarkStar program early in its development due to knowledge gained in the process and led to a decision not to acquire the Outrider system on a sole-source basis.[133] However, the changed defense environment and budget pressures also compelled the DoD to choose between the Global Hawk and DarkStar, and DoD chose to cancel DarkStar.[134] The ACTD process has been relevant to three recent DARPA UAV development programs: Global Hawk, DarkStar and the UCAV.

With its efforts in Micro Air Vehicles, DARPA is again pushing UAV technology forward. Efforts in small, lightweight propulsion, sensing, and communication technologies all need to be undertaken if such vehicles are going to be developed and fielded by the Services. These systems will likely raise operational issues that may be stressing to the military users, but the experimentation processes now being used may reduce the resistance to their use. Moreover, these vehicles may not face the same competition from other systems that has confronted larger UAVs.

OBSERVATIONS AND CONCLUSIONS ON DARPA IN UAV

A number of observations and conclusions can be made on DARPA's RPV/UAV activities from this assessment. This section will proceed as follows: 1) the DARPA role in RPV/UAV development, 2) how the process worked, 3) why some of the problems that exist may have occurred, and 4) some steps to improve the process.

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131 See, for instance, Congressional Budget Office, *Options for Enhancing the DoD UAV Programs*; and US General Accounting Office, *Unmanned Aerial Vehicles: DoD's Demonstration Approach has Improved Project Outcomes*, Washington, DC: US Government Printing Office, August 30, 1999, pp. 4–5.

132 US General Accounting Office, *Unmanned Aerial Vehicles: DoD's Demonstration Approach,* p. 4.

133 Ibid., p. 1.

134 Federation of American Scientists. *Intelligence Resource Program: RQ-3A DarkStar Tier III Minus*. At <www.fas.org/irp/program/collect/darkstar.htm>.

Roles of DARPA

DARPA has played an important role in the development of RPV/UAVs. That role continues. While the Agency's role is often discussed in terms of particular RPV/UAV systems (e.g., its role in Amber, or Global Hawk), DARPA's most important efforts have not been in individual systems. Rather, DARPA has been instrumental in developing:

- Enabling technologies that have been essential to developing the overall UAV capabilities. DARPA has sponsored important technological developments in sensors, command and control, structures, operational concepts, and acquisition processes. The ability of the current UAVs to communicate, navigate, locate, and report on targets derives largely from previous DARPA investments.
- Ideas on how to employ these new technologies. DARPA sponsored studies on how RPVs and UAVs could be used, what type information might be obtained, and which targets attacked. According to its own testimony, the Agency was more successful on defining operational roles for longer-range vehicles than for the short-range tactical vehicles.
- A workable acquisition strategy to help get the technology into the field. DARPA used its authority under Section 845 to streamline the acquisition process. It also developed a strategy of using ACTD to develop, prototype, and facilitate the acquisition of UAV.

DARPA's record of work with RPVs and UAVs goes back over three decades—almost to the establishment of the organization. Although it appears that DARPA may have been more engaged at some times than at others (here our assessment is hindered by the lack of information on classified systems), our research suggests that consistent effort was aimed at RPVs and UAVs and the technologies that might enhance their performance. This effort might be judged to be something akin to the DARPA effort in the information technology field that involved a long-term investment on fundamental enabling technologies. A similar approach apparently was undertaken in the UAV field too, although possibly not as systematically. UAVs are going to play an increasingly important role in future combat, whether it is theater conflict or counterterrorism. In that regard, it is clear that in the case of this technology development, DARPA has played an important role relative to the RMA.

How the Process Worked

There are two ways to consider how the DARPA RPV/UAV support process worked. At one level there is a need to understand the mechanism or flow of work. Where did ideas come from (internally or externally driven), how were the ideas pursued (competitive firms or long-term associations), how were the results marketed (partners with the Services or performing a "hard sell"), and what were the mechanisms for implementing them (pass off to Services, ACTD)? At a second level there is a need to make some assessment of how well the process functioned.

The Mechanism

It appears that the initial efforts were externally driven. The Navy had a problem with the DASH, and DARPA was asked to help. This external direction continued with support of Service RPV activities in Vietnam and developments for longer-range vehicles to penetrate Chinese airspace. By the mid-1970s, however, the dynamics began to shift. Malcolm Currie as the DDR&E was intent on revitalizing the scientific effort to meet the Soviet threat, and DARPA was enlisted in the effort. RPVs fit into the strategy of seeing and hitting deep targets and leveraging US technology to destroy Soviet forces before they arrived on the battlefield. The DARPA management signed on to develop technologies that supported RPVs and UAVs. By the end of the 1970s DARPA was transferring the technology to the Services for further development and testing. It was also transferring the technology to allies (Israel). At the same time, it appears that the Agency was also involved with the CIA in developing longer-range UAVs. All of these UAV activities were relatively small potatoes, and the firms involved tended to be smaller. Some firms were consistently involved (for example, Ryan Aeronautical, subsequently Teledyne Ryan and now Northrup Grumman Ryan). There has generally been more competition in short-range tactical systems than in longer-range systems and increasing interest in UAVs in the 1990s as the potential for larger procurements appeared to develop (the UCAV, for example). Ideas have come from the outside (the Condor, the Amber, DarkStar), but many of the technologies have been nurtured by DARPA before being reintroduced into the system (Pioneer, Gnat-750). The initial mode of transfer from DARPA program to Service program appears to have been a relatively abrupt transfer of the proven concept—DARPA did the science the Services and industry did the engineering and development. But after almost two decades of difficulty and failure, the mode changed to a more extended transfer in the form of an ACTD. This changed process also helped with the selling of the technology. It could help build support for the system and overcome the competition of other existing systems. Whether that model is sufficiently developed remains to be seen.

Evaluation of the Process

The short answer as to how well the process worked is "not as well as one would like." As occurred with Assault Breaker and the stealthy surface ship, *successful demonstration of the technology for RPV/UAVs did not lead to early acceptance and deployment of the vehicles*. The delay in fielding appears to have happened for reasons that are common with both the other efforts. Some of the issues that have surfaced either in interviews form participants or from examination of the records and bear consideration are listed below.

- There were often differences between the expectations of the DARPA PM and those of the Services on performance (unprepared field versus prepared airstrip) and the level of development (proof of principle versus need for extensive engineering) needed to transition a program. These differences had an impact on the ability of the system to successfully continue on into a deployed system. The RPVs often did not appear to have measured up to the expectations of the Services, or in some cases those expectations changed as the Service's requirements escalated.
- Costs were difficult to control. This appears to have been a function of both mission creep (hanging more gadgets on the vehicles in hope of gaining support) and the resulting difficulties with development of increasingly complex systems. Development cost increases reduced expected procurement numbers. That drove up unit costs, which in turn made everything less attractive.
- Contractors underestimated the production costs.
- Reliability suffered for increased performance. In the end, if it could not be made to work consistently the Services did not want it.
- The systems did not fit within the existing force structure and did not have strong service champions. Without better planning they could not survive the budget battles.
- The developments often did not fit with existing operations and doctrine. The front-line soldiers wanted an independent capability to "see over the hill." That meant a simple, rugged capability vehicle, or a more complex vehicle that would reliably supply information to these front line forces. A simple, rugged vehicle still does not exist. Reliable information may.
- DARPA's Project Managers often lack contact and collaboration with the three Services. This is not necessarily true of DARPA's higher echelon management, but the contact between Project Managers and the mid-level personnel in the three Services was very unsatisfactory.
- The MOUs between DARPA and the Services (as well as among the three Services) were not satisfactory. These may provide only very general guidance, which may or may not be "translated" into actual working relationships.

- Some of the DARPA's projects continue for several years and even a decade, and the absence of DARPA's reporting to the Services over such long time periods results in confusion.
- Mission creep was a major issue. One result of all these issues is that when the Services completed their changes on the individual systems, the resulting vehicle often cost too much, was not reliable, was difficult to operate, and was hard to fit into the force structure and operations. Mandate from above (Navy Secretary mandating purchase and deployment of a system) and use of ACTDs appear to have reduced these problems.

VII. DISCOVERER II

Rob Mahoney

OVERVIEW

Discoverer II (DII)[1] was a proposed satellite-based sensor demonstration program. The objective was to provide a revolutionary improvement in the timeliness and quantity of battlefield information, provided directly to tactical commanders in a system that would be tasked by these commanders. Specifically, DII was to provide three major new types of capabilities:

- Deep, broad area, near-continuous, near-real-time, ground mobile target information to allow tracking of adversary forces
- High resolution (about 1 meter) three-dimensional synthetic aperture radar imaging to support precision targeting
- Tasking by joint task force commanders, who would also directly receive downlinked data on both fixed and mobile targets

Based on DARPA-developed technologies, the effort was to be co-sponsored by DARPA, the Air Force, and the National Reconnaissance Office (NRO). In a parallel effort, the Army was prepared to modify an existing tactical ground station to provide an interface for the ground force commander. However, in the National Defense Appropriations Bill for Fiscal Year 2001, Congress terminated the DII program. The history of DII provides lessons learned that are relevant for future situations in which DARPA or other DoD organizations propose inherently expensive programs directed at achieving qualitative improvements in military capabilities.

THE DISCOVERER II PROGRAM

In its February 2000 RDT&E Budget Justification (R-2), DARPA outlined the background to and goal of the DII program:

> The Discoverer II program is a DARPA, Air Force, and National Reconnaissance Office (NRO) joint initiative to develop and demonstrate an affordable space-based radar (SBR) with Ground Moving Target Indication (GMTI) and Synthetic Aperture Radar (SAR) imaging capabilities that will revolutionize reconnaissance, surveillance and precision geolocation support to the tactical warfighter.

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1 The program's title reflected the revolutionary objectives to be pursued in the proposed effort. Discoverer was the public cover name for the Corona program, which provided the first satellite imagery—a completely new capability.

Discoverer II is the direct descendant of the DARPA STARLITE initiative. In January 1998, the Defense Science Board Task Force on Satellite Reconnaissance issued its report. The Task Force recommended that a modified STARLITE program be initiated, as a Military Space Radar Surveillance Program, in an effort to achieve broad-area, all-weather, near-continuous radar access that could be integrated with military operations. Two central findings of the Task Force were that an on-orbit demonstration would likely be needed, and that a technical risk reduction program should be undertaken in advance of the demonstration to bring leading edge, higher risk technologies to bear to meet both warfighter needs at a lower cost, and to enhance systems maturity thereby facilitating a more direct and rapid transition to a follow-on operational concept.

Discoverer II is a staged technology R&D program. In the first phase industry will conduct detailed trade studies necessary to define both an affordable objective space-based radar system for the 2010 timeframe and a demonstrator system for the 2005 timeframe that shows that it addressed the highest risk of the proposed objective capability. Concurrent with the performance of trade studies by Discoverer II system integration contractors, results of the risk reduction efforts will be exploited to ensure Discoverer II R&D demonstration can be pursued with acceptable risk. Specifically, the technologies to be pursued include: 1) developing a low-cost multi-mode GMTI/SAR space-qualified electronically scanned antenna, 2) developing low power Microelectromechanical Systems (MEMS) for scanning radar modules (10x reduced power requirement), and 3) spare band processing for data compression allowing on-ground processing with moderate rate communications links, and Automatic Target Recognition (ATR) quality range profiling. The proposed satellite system will also use an interferometric synthetic aperture radar (IFSAR) capability to produce high-accuracy digital terrain elevation data (DTED) to support both battlefield visualization (BV) and precision guided munitions (PGM) targeting (precision geolocation accuracy theater wide). If industry trade studies, informed by the results of the Discoverer II risk reduction initiatives, show an affordable objective system is achievable, Phase II will build and fly two GMTI/SAR technology demonstration satellites. The R&D demonstration will validate the technical feasibility of advanced C4ISR capability complementing/extending current Unmanned Air Vehicle (UAV)/aircraft architectures. The demonstration will show how an objective system can provide deep-look access to denied area, and near continuous coverage from diverse look angles over the battlefield. Objectives for the demonstration include mobile target detection, tracking, and targeting; intelligence preparation of the battlefield; wide area search and precision engagement with direct downlink to the warfighter. The Discoverer II demonstration program will allow the joint community to make an informed decision on future operational Space Based Radar after the FY 2005 flight demonstration.[2]

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2 *RDT&E Budget Item Justification Sheet (R-2 Exhibit)*, "Sensor and Guidance Technology," PE 0603762E, Project SGT-02, February 2000.

OPERATIONAL NEEDS

Joint Vision 2020 and other recent defense planning guidance cover two capabilities relevant to DII: (1) dominant battlespace awareness with real-time all-weather continuous coverage, and (2) precision engagement capabilities that include high-resolution situational awareness and sensor-to-shooter support.[3] These needs derived in part from the US experience during the Gulf War, which revealed significant shortfalls in imaging capabilities. There were situations in which imagery collected by national systems was not provided in usable forms to tactical commanders on timelines that would allow the information to be exploited.[4] This was particularly a problem for information concerning mobile forces. Also, satellite imagery coverage was not continuous during the Gulf War and Iraqi forces were able to move without detection in the periods between satellite overflights. Finally, even when available, current imagery systems are degraded by nighttime and by overcast weather. During operations in the Balkans, cloud cover impeded the detection and tracking of Serbian armored forces.[5]

Existing imagery satellites were developed to respond to the needs of multiple user communities. Applications include arms control treaty verification, strategic planning, and support to tactical operations.[6] Each of these missions has different requirements; a single system solution for the entire set necessarily involves compromises. Furthermore, priority conflicts can develop, particularly during conflicts, when the needs of joint theater commanders greatly increase. There has also been a revolution in guidance and accuracy.[7] It is now possible to develop delivery systems that have accuracies on the order of one or a few meters. However, it is not possible to make use of some of these improvements unless the locations of targets are known with accuracies comparable to the weapon systems. For low-flying cruise missiles or aircraft, three-dimensional data is required for route planning.

Full deployment of a full (up to 24 satellites) DII constellation would provide a major improvement in these capabilities. Synthetic aperture radar would not be impacted by night or cloud cover. Revisit rates would be on the order of 15 minutes, making tracking of movable targets possible. A direct data link to theater commanders and tasking of collection by theater

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3 A good overview of these requirements with emphasis on relevance for the NRO mission is provided in *Defining the Future of the NRO for the 21st Century*, Final Report, Executive Summary, Report to Director National Reconnaissance Office, August 26, 1996.

4 "Lessons Learned Above the Gulf," *Space News*, March 4, 1991, p. 14.

5 James T. Hackett, "Keeping Our Lead in Space," *Washington Times*. June 23, 2000. <http://www.cdiss.org/col00june23.htm>.

6 *Space Digest,* Volume 8: Issue 379, September 20, 1988.

7 John S. Foster and Larry D. Welch, "The Evolving Battlefield," *Physics Today*, December 2000.

commanders would provide a revolutionary improvement in responsiveness. As planned, DII would provide geolocation information with an accuracy of roughly 1 meter—DTED level 5.

PROGRAM HISTORY

Since the mid-1980s, there have been arguments for use of small, light satellites (lightsats) as replacements for or adjuncts to traditional satellites. Three different concepts have been associated with lightsats:

- Satellites that are literally lighter in weight and hence less expensive and capable of being launched at lower cost.
- Satellites plus launchers developed to take advantage of lower payload weights.
- A change in paradigm/operational concept in which a theater command is given direct access to data from the satellite and, in some cases, the ability to task the system, as opposed to the traditional model in which satellites are national assets that download to national organizations which process and forward information to theater command and other users.

DARPA's interest in lightsat technologies (in one or all of the three senses) dates to the mid-1980s. The first lightsat developed by DARPA's Advanced Satellite Technology Program was the Global Low-Orbit Message Relay (GLOMR) communications satellite launched by a space shuttle in October 1985.[8] MACSAT was a DARPA technology demonstration satellite orbited in May 1990. It carried two UHF transmitters in a low polar orbit. It was a store-and-forward satellite capable of data uplink/downlink. During the Gulf War, a squadron of the 2nd Marine Aircraft Wing was given exclusive use of this satellite, which it used to transmit logistics information to its US headquarters. The squadron gave a favorable evaluation of this link, with particular emphasis on the concept of dedicating the satellite for use by a single unit.[9] DARPA experiments and demonstrations continued after the Gulf War, e.g., the 1994 DARPASAT payload of GPS receiver and data processor technologies.[10]

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8 *Affordable Spacecraft: Design and Launch Alternatives*, Washington, DC: Office of Technology Assessment, US GPO, 1990.

9 Matt Bille and Robyn Kane, "The High-Low Mix: A New Concept in Military Space," *11th AIAA/USU Conference on Small Satellites*, 1997, p. 2.

10 Encyclopedia Astronautica, "Chronology 1994," <http://www.friends-partners.ru/partners/mwade/chrono/19941.htm#4516> and "DARPASAT Chronology," <http://www.astronautix.com/craft/darpasat.htm>.

The DARPA Starlite concept was advanced in 1997 following a DARPA-sponsored study.[11] An initial challenge was the perception within NRO that the program was redundant with the Future Imagery Architecture.[12] The January 1998 report from the DSB task force on Satellite Reconnaissance (appended) played an important role in the development (February 1998) of a consensus approach whereby a joint program office would be established for a program to be co-sponsored by the Air Force, NRO, and DARPA.[13] In April 1998 the program was renamed Discoverer II.[14]

An initial problem was encountered in June 1998, when the House Appropriations Committee recommended elimination of DII funding because DoD had not provided the required notification for a major new start. Press coverage at the time noted that concurrent issues involved the cost of the demonstration (with the Air Force providing assurances to OSD concerning cost projections), and the absence of a formal requirements document for DII.[15] At the same time, the cost of the NRO FIA architecture was an issue.[16] These issues were overcome, and FY 1999 funding was provided for DII.

In February 1999, DARPA selected contractors for the first phase of DII.[17] In September 1999, NRO announced award of a contract to Boeing for development, launch integration, and operation of FIA; this was the largest and last component in the FIA program.[18] Again, the House Appropriations Committee expressed opposition to DII, but the full Congress elected to allow initial efforts to continue.[19] This involved funding of \$40 million (a reduction of \$65.8 million from the request) and the restriction that this funding could only be used to complete the phase one study portion of the program and any associated program management costs.[20]

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11 *Discoverer II (DII) STARLITE*, <http://www.fas.org/spp/military/program/imint/starlight.htm>.

12 Pamela Hess, "Starlite Shelved While USAF, NRO Work Out Roles, Redundancy Issues," *Inside the Air Force,* May 23, 1997.

13 "Critical Intelligence," *Inside the Pentagon*, February 5, 1998.

14 *Discoverer II (DII) STARLITE.* <http://www.fas.org/spp/military/program/imint/starlight.htm>.

15 Gigi Whitley, "Citing Lack of Notification, Committee Deletes Discoverer II Funds," *Defense Information and Electronics Report,* June 26, 1998.

16 Pamela Hess, "NRO Imagery Architecture Under Congressional Fire," *Defense Information and Electronics Report,* July 17, 1998.

17 "Discoverer II Contractors Selected," *Air Force News*. February 22, 1999.

18 *Press Release*. National Reconnaissance Office, September 3, 1999.

19 SSgt. Michael Dorsey, "Funding Cut Threatens Space Project," *Aerotech News and Review,* August 27, 1999.

20 Conference Report on H.R. 2561, October 8, 1999, H9813.

Phase Ib contract awards for DII were announced in May 2000.[21] However, as noted previously, the House Appropriations Committee again recommended that the program be canceled. A number of members of Congress wrote in support of DII, noting that CINC SPACECOM had characterized it as his number one technology program.[22] Secretary Cohen mentioned DII in his letter accompanying DoD appropriations appeals.[23] Notwithstanding these appeals, the appropriations conference elected to terminate the program. Noteworthy is the fact that, as of July 2000, when House appropriators had again expressed opposition to the program, the Air Force had not yet completed a formal requirements document (Mission Need Statement) for Discoverer II.

DIFFERING PERSPECTIVES ON THE DISCOVERER II PROGRAM

Common Issues

Cost was very much a consideration. DII was an expensive program. The estimated cost (Air Force FY 2002–FY 2007 Program Objective Memorandum) was $702 million, plus an additional cost of perhaps $110 million for launch vehicles. All of the organizations involved in the DII program and decisions were impacted by funding constraints. All were under pressure to re-justify and re-size their investments. Under these circumstances it was difficult to find the resources needed for a major demonstration and/or the acquisition program that was proposed to follow a successful demonstration.

In opposing the DII program, the House Appropriations Committee argued that costs might exceed $1 billion, which, in its view, made the program of a magnitude comparable to that of fully operational satellites and hence unaffordable given the limited operational benefits that would result from a technology demonstration.[24] The final legislation terminating the program also stated that, if successful, the follow-on program might cost $25 billion, a cost that could not be sustained without a substantial increase in the Air Force budget.[25]

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21 "TRW/Northrop Grumman Team Awarded Discoverer II Contract Option for Competitive Concept Definition," Press Release, TRW, Inc., May 5, 2000.

22 "Letter from Senator Kyl and other Senators to Senator Ted Stevens," *Inside the Air Force*, July 14, 2000.

23 "Text: Cohen Letter Accompanying DoD Appropriations Appeal Package," *Inside the Army*, July 17, 2000.

24 Amy Butler, "House Committee: High-Cost, Questionable Need Doomed Discoverer II," *Inside Missile Defense*, May 31, 2000.

25 House Report 106-644, *Department of Defense Appropriations Bill, 2001*, Discoverer II.

Air Force

Air Force interest in DII was prompted by the opportunity to achieve completely new types of capabilities. The JSTARS aircraft was a primary platform for ground surveillance missions. In the 1997 Quadrennial Defense Review, the JSTARS fleet was cut from 19 to 13 aircraft, apparently on the assumption that NATO allies would acquire 6 units. When NATO allies opted not to do this, changes in plans and programs were required. Options given consideration included reversing the JSTARS decision and acquiring additional aircraft, procuring U-2 aircraft with mobile target indicators and synthetic aperture radar, using unmanned aerial vehicles, and employing space-based radar.[26] The space-based radar option also aligned with an Air Force corporate decision to transition more surveillance/reconnaissance functions to space and to give increased priority to space-related research and development.[27]

The DSB Task Force on Satellite Reconnaissance summarized what it saw as the Air Force's perspective on the issues involved in Starlite (the predecessor to DII):[28] The Air Force had decided to migrate important surveillance and reconnaissance functions to spacecraft. This would overcome limitations of current and planned aircraft systems. It believed that these space sensors needed to be fully integrated into operational military systems. Perceived advantages of Starlite/DII were more continuous access, direct and timely reporting to support targeting, and freedom from burdensome intelligence community security classifications and procedures. It regarded Starlite/DII as similar to JSTARS in operational concept without the range and shadowing issues and the operational and logistics footprints associated with a multiple aircraft system.

A complication, both within the Defense Department and in Congress, involved the Air Force's attempt to fund some of its Discoverer II investment using science and technology (S&T) funding in place of engineering manufacturing development resources.[29] This was opposed by

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26 Pamela Hess, "Air Force Standing by Decision Not to Reinstate JSTARS Production," *Inside the Air Force*, April 2, 1998.

27 Lieutenant General Gregory S. Martin, Principal Deputy Assistant Secretary of the Air Force (Acquisition), *Presentation to the Senate Armed Services Committee Subcommittee on Emerging Threats and Capabilities*, April 1999.

28 *Defense Science Board Task Force on Satellite Reconnaissance,* Washington, DC: Defense Science Board, 1998, <http://www.fas.org/spp/military/program/imint/dsb-980100.htm>.

29 "The Budget Situation," *Special Reports*, The Air Force Association, <http://www.afa.org/media/reports/future5.asp>.

DoD S&T management and was of concern to some members of Congress.[30] While not cited by Congress as a reason for canceling DII, this did illustrate the pressures that the Air Force budget was under, which was a House Appropriations Committee issue.

Army

The Army did not contribute funding to the proposed DII demonstration. However, the Army did program the funds needed to modify the existing enhanced tactical radar correlator (ETRAC) system to support the demonstration. Army interests in the demonstration included determining the feasibility and utility of delegating collection management authority to a tactical commander, demonstrating the imagery to be developed, demonstrating rapid-response changes to tasking by an Army corps, and appraising the utility of having a corps directly commanding satellite payloads.[31]

DARPA

As presented by the DSB Task Force on Satellite Reconnaissance, the DARPA perspective was that NRO had, over time, become more focused on evolutionary improvements to respond to customer needs. DARPA, on the other hand, had the mission of high risk, revolutionary technologies. Starlite/DII involved high risk technologies, necessitating an on-orbit demonstration. Because downlinked data and products would not be handled using intelligence procedures, payoffs were seen as involving the following: 1) the operational value of nearly continuous access; 2) high resolution target data to support precision engagement; 3) reduced cost of ownership; 4) easier access by tactical units (direct downlinks); and, 5) opportunities for international cooperation. As a riskier, longer-term program, Starlite/DII was not seen as competitive with NRO's planned Future Imagery Architecture systems.

NRO

As summarized by the DSB Task Force on Satellite Reconnaissance, NRO's perspective on the points at issue in the DII decisions was that NRO had to replace aging surveillance systems and had used a well-defined requirements definition and acquisition process to define the

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30 For example, the statement of Senator DeWine, "I am very troubled about the Air Force's proposal to use Air Force S&T resources to fund the Space Based Laser and Discoverer II (space-based radar) program beginning in FY 2000. It is our understanding that these previously non-S&T programs were inserted into the FY 2000 Air Force late in the budget process, while providing no additional funds to cover the costs of current S&T programs...," Congressional Record – Senate, March 25, 1999, S34423.

31 "Space," Section Q, *Army Science and Technology Master Plan*, 1998, <http://www.fas.org/man/dod-101/army/docs/astmp98/>.

Future Imagery Architecture (FIA).[32] DARPA's proposed Starlite program was regarded as problematic by NRO because:

1) It could be regarded as competing with a segment of FIA without reference to the requirements formally developed with the FIA program or a defined relationship with the rest of the FIA system.

2) Higher risk technologies were to be employed.

3) There was a potential future conflict between the role of NRO (national intelligence systems) and the Air Force's plans to migrate key surveillance and reconnaissance capabilities from aircraft to spacecraft to provide improved operational capabilities. On this path, the Air Force would expect to be the lead agency following a successful demonstration.

4) There was concern that NRO might become the bill-payer for the DARPA program even though it did not have sufficient funding for FIA.

The approach taken by NRO for development of a new architecture for imagery satellites was developed in a context defined in part by three external reviews:

- *Preparing for the 21st Century: An Appraisal of US Intelligence* (Brown/Rudman Commission). Chartered by Congress in October 1994, this Panel's report was published on March 1, 1996.
- *Director Central Intelligence Small Satellite Review Panel* (Hermann Panel). Commissioned by Congress in 1995, this panel's report was delivered in June 1996.
- *Defining the Future of the NRO for the 21st Century* (Jeremiah Panel). This report was delivered in August 1996.

The Brown/Rudman report addressed space reconnaissance as one topic in a comprehensive review of intelligence community capabilities and requirements.[33] Its appraisal noted that the then current US space reconnaissance capability comprised a small number of large and expensive systems that was vulnerable to the failure of any single system. Operational costs in the billions of dollars per year, plus per system costs, put great pressure on the intelligence community to search for alternatives, find efficiencies, and scrutinize the requirements addressed. To this end it recommended adoption of a two-tier approach. The top

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32 *Defense Science Board Task Force on Satellite Reconnaissance*, January 1998.

33 *Preparing for the 21st Century: An Appraisal of US Intelligence*, Report of the Commission on the Roles and Capabilities of the United States Intelligence Community, March 1, 1996, <http://www.fas.org/irp/offdocs/report.html>.

tier would continue to involve US-unique capabilities made up of the most sophisticated systems directed at the most critical requirements. This would be complemented by a second tier of less capable systems developed and operated in conjunction with allies and friendly states, to include the application of commercial technologies and systems.

The Commission noted that deployment of larger numbers of smaller, less expensive, satellites would have advantages, to include reduced launch costs, more frequent revisit times and improved global coverage. However, it believed that it was premature to endorse increased reliance on small satellites as replacements for current reconnaissance systems. A constellation of such smaller satellites might not be cheaper than a smaller number of current systems. Furthermore, it believed it was uncertain that such smaller satellites could accomplish all of the missions of current systems. It did, however, suggest that smaller satellites might be part of the second tier described previously.

For immediate purposes it is important to note how the Commission framed the issue. The question was the ability of a constellation of smaller satellites to affordably provide mission capabilities equivalent to current technology larger satellites. In the case of DII, a key argument was that it would provide theater commanders with new mission capabilities, e.g., continuous deep observation of mobile targets and very high resolution geolocation information.

The DCI Small Satellite Review Panel had a different perspective on the subject of small satellites.[34] Referencing the same current state of the art in imagery satellites as the Commission, this panel concluded that:

> ...now is an appropriate time to make a qualitative change in the systems architecture of the nation's reconnaissance assets...
>
> We see the opportunity to move towards an operational capability for the country, at least for imagery systems, that consists of an array of smaller, cheaper spacecraft in larger numbers which is at least as useful as those currently planned and to transport them to space with substantially smaller and less costly launch vehicles.

At the same time, this panel argued that there was a need to provide a mechanism for creating high-end systems that would be beyond the capabilities of other societies.

The DCI and NRO endorsed the Hermann Panel's conclusion *that smaller is better*.[35] NRO indicated that it was moving toward a smaller class of satellites for the reasons advanced in

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34 Larry Combest, Chairman, House Permanent Select Committee on Intelligence. Press Release: *Report by the DCI's Small Satellite Review Panel,* June 28, 1996.

35 *NRO Statement on Small Satellites*, July 1, 1996, <http://www.nro.gov/PressReleases/prs_rel6.html>.

the Panel's report. The NRO statement indicated that the key issue was not whether to move toward smaller satellites. Instead, the key questions were 1) how small should satellites be? and 2) how to accomplish the transition without interrupting support to policymaker and operational customers?

The Jeremiah Panel did not focus on the relative merits of small vs. large satellites for imagery and related missions.[36] However, it did develop a number of recommendations, conclusions, and observations relevant to the issues associated with the DII decision:

- An expanded role for space reconnaissance in support to military operations would be a major factor impacting the 21st century mission of NRO. One effect, not noted by the Jeremiah Panel, might be for NRO to move into the same niche that DII was attempting to fill: direct technical support to theater commanders.
- Notwithstanding this expanded role, *the exact implications of this vision of future military ISR needs for space reconnaissance are not totally clear because of uncertainties at this point over the relative roles of airborne reconnaissance systems, nonintelligence space surveillance systems, and space reconnaissance systems.*[37]
- The future mission of NRO should be to revolutionize space reconnaissance.
- The Gulf War marked a paradigm shift in which coalition partners have emerged as a new class of users whose needs must be satisfied.
- The needed information superiority will require, in addition to continuation of current services, a revolutionary path to an entirely new architecture to provide near-continuous global coverage and long dwell.
- NRO is no longer universally regarded as being at the leading edge of technology.

DSB SATELLITE RECONNAISSANCE REVIEW

In its budget submission for the DII program, recommendations from the DSB Satellite Reconnaissance Review are the primary frame of reference used by DARPA. Hence, this task force's five recommendations are critical for understanding decisions concerning DII:[38]

1) FIA should proceed on schedule, decoupled from DARPA's Starlite/DII. The DARPA effort is higher risk than appropriate for, and hence not competitive with, FIA.

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36 *Defining the Future of the NRO for the 21st Century,* Final Report, Executive Summary, Report to Director National Reconnaissance Office, August 26, 1996.

37 Ibid., p. 8.

38 *Defense Science Board Task Force on Satellite Reconnaissance*, p. 7. Also important are this task force's appraisals of the perspectives of the organizations involved in satellite reconnaissance programs, as presented previously. Because of its importance, the text of this DSB report is appended.

2) Starlite system objectives are important for military operations. The task force agreed with DARPA's arguments that these objectives are best achieved through proliferation of low-orbit satellites. Such satellites must be lower cost than in the past. These systems should be integrated into military force structures, weapon systems, and ongoing military operations.

3) FIA should be open to some Starlite/DII attributes. Increased attention should be given to achieving moving target indicator and rapid revisit image coverage on an evolutionary schedule. Existence of FIA should be unclassified and data SECRET or lower level. Effort is needed to improve integration of FIA systems with military operations.

4) A modified Starlite program should be initiated. The Task Force recommended that DoD undertake a program to create a Military Space Radar Surveillance Program to achieve broad-area, all-weather and near continuous radar access for integration with military operations. The program should bring higher risk, leading edge technologies to bear at lower cost. A technical risk reduction program should be planned and executed. An on-orbit demonstration is likely to be needed, but this should be preceded by significant risk reduction efforts so that system definition is more mature and can lead more directly to an operational prototype. Integration with combat forces should be emphasized. In line with this, there should be an eventual acquisition, organization, and training role for the Air Force. DARPA and NRO should participate to provide their unique expertise.

5) Roles and relationships of defense organizations need to evolve for these missions.

    - NRO should continue to be the lead for acquiring and operating systems that are primarily for intelligence and strategic reconnaissance missions.

    - The Military Departments should have an increased role in space sensors acquired primarily for support to ongoing military operations. After DARPA has brought technologies to maturity, the Air Force is the logical organization to have Title X responsibility.

    - NIMA must assure management of operational and intelligence space and airborne imagery systems. NIMA must perform the role of rationalizing needs, creating systems and procedures for processing and exploitation, and insuring proper application to military purposes.

    - The Joint Staff should continue to develop its system decision process for these mission areas. The Task Force was impressed with the progress reported by J8 in developing a decision for surveillance and reconnaissance capabilities that engaged the system developers, Services, and CINC staffs. The success achieved with the Space Based Infrared (SBIR) System decision and the process projected for FIA using the Senior Warfighters Forum is impressive. In our view, forcing the operational users and the system advocates into the same venue where resource constraints and military value can be evaluated together is a superior way to make the necessary trades for the Nation.

END GAME

In the authorization process for the FY 2001 defense budget, both the House and Senate committees supported DII, but not at the level of $129 million requested by DoD. Instead, they authorized $30 million for continued space-based radar risk reduction and technology development. Their rationale for support at a lower level of funding was as follows:

> The conferees strongly support an effort to develop the technologies and operational concepts that would enable deployment of an SBR system to perform ground moving target indications (GMTI), digital terrain elevation data collection, and synthetic aperture radar (SAR) imaging. The conferees believe that such a system might offer a cost-effective way to provide valuable new technical capabilities while complementing, and perhaps replacing, the capabilities of other systems. The conferees believe that the Secretary of Defense should evaluate options for eventual development and deployment of an operational SBR system. In addition, the conferees believe that the Air Force, US Space Command, the Defense Advanced Research Projects Agency, and the National Reconnaissance Office should continue to work together to mature the necessary technologies, conduct an analysis of alternatives, and develop operational concepts to provide better information for this evaluation and to support a potential deployment.
>
> Therefore, the conferees direct the Secretary of Defense to prepare an SBR roadmap to guide this overall effort. The roadmap should address several concerns: (1) the operational requirements for space-based GMTI, DTED, and SAR capabilities; (2) the relationship of an SBR system to other current and planned air and space-based assets that might provide such capabilities; (3) the technologies needed to enable an affordable and operationally effective SBR system; and (4) if a requirement for an SBR system is established, whether a space-based technology demonstrator would be cost-beneficial prior to an SBR acquisition. The conferees direct the Secretary to submit a report to the congressional defense committees on the SBR roadmap by May 1, 2001.[39]

In consideration of the proposed FY 2001 defense appropriation, the House Appropriations Committee opposed the DII program. Senate appropriators supported continuation. Consequently, its fate was determined in the appropriations conference, where the House Appropriations Committee's decision to terminate the program was sustained:

> The Air Force, Defense Advanced Research Projects Agency, and the National Reconnaissance Office collectively requested $130,000,000 for the Discoverer II satellite technology demonstration program. The Committee recommends no funding, a decrease of $130,000,000. The fiscal year 2000 Defense Appropriations Act provided sufficient funding for the Discoverer II program to conclude the phase I studies and analysis portion of the program along

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[39] House Report 106-945.

with related risk reduction efforts. With phase I now funded to completion, the Committee recommends that the Discoverer II program be terminated.

The Committee makes this recommendation for the following reasons: (1) Discoverer II has no documented requirement or concept of operations; (2) the cost of engineering and manufacturing development phase of the program, which the program office estimates at $702 million and which will in all likelihood exceed $1 billion, is of a magnitude ordinarily associated with the development of fully operational satellites and therefore unaffordable given the limited operational benefits of a technology demonstration program; (3) the Department has conducted no trade-off analysis between Discoverer II and other systems and processes that could deliver ground moving target indication data to warfighters; and, (4) the Department has failed to analyze the impact a Discoverer II constellation would have on an already overtaxed imagery processing, exploitation, and dissemination system.

Even if successful, there is no guarantee the Air Force could ever build, launch, operate, and maintain a Discoverer II constellation without a substantial top line increase to its budget. By some estimates the cost of a fully functional Discoverer II constellation could reach $25 billion. In face of other severe shortfalls in space and aircraft modernization the Committee concludes that Discoverer II is of low priority and recommends its termination.

The Committee discusses its recommendation more fully in the classified annex to this report.[40]

DEVELOPMENTS SUBSEQUENT TO CANCELLATION OF DISCOVER II

Following termination of the DII program, increased attention was given to appraisal of requirements for a space-based radar. This included an Analysis of Alternatives and the development (in 2001) of a Multi-Theater Target Tracking Capability (MT3C) Mission Needs Statement (MNS).[41] The National Space Architect initiated a related multi-service, multi-agency effort to develop an SBR Roadmap.[42]

A space-based radar (SBR) joint program has been established. The SBR program is intended to develop an ISR system capable of providing ground moving target indication, synthetic aperture radar imaging, and digital terrain and elevation data over a large portion of the

40 House Report 106-644.

41 *Space-Based Radar (SBR)*, Fact Sheet, United States Air Force, June 2001, <http://www.losangeles.af.mil/smc/pa/fact_sheets/sbr.htm>. Amy Butler, "Rapid-Deploy Space-Based Radar Could be Launched in Fiscal Year 2006," *Inside Missile Defense*, March 20, 2002.

42 General Ralph E. Eberhart, USAF, Commander in Chief, North American Aerospace Defense Command and United States Space Command, *Testimony*, United States Senate Arms Services Committee, Strategic Subcommittee, 11 July 2001, p. 13.

Earth on a near-continuous basis.[43] USAF Space and Missile Systems Center serves as the lead with principal participation from USAF Electronic Systems Center, the National Reconnaissance Office, US Army, and US Navy.[44]

In July 2001, the Under Secretary of Defense (Acquisition, Technology & Logistics) directed a requirements and risk reduction effort to provide the space element of a future air/space Intelligence, Surveillance, and Reconnaissance (ISR) system to satisfy the MT3C MNS no later than fiscal year 2010. The SBR program is intended to develop an ISR system capable of providing ground moving target indication, synthetic aperture radar imaging, and digital terrain and elevation data over a large portion of the Earth on a near-continuous basis.[45] USAF Space and Missile Systems Center announced a meeting with industry for SBR in January 2002.[46]

The President's Budget Estimates for fiscal year 2003 included $91 million for space-based radar.[47] The fiscal year 2002 President's Budget had requested $50 million for SBR and cited it as one of the transformation programs in the amended fiscal year 2002 budget request.

ISSUES AND POTENTIAL LESSONS LEARNED

Before looking at reasons why DII failed, it is useful to review the many things it had going for it. Specifically:

- This was a joint program, with an MOA in place and a Joint Program Office. DARPA, Air Force, and NRO were on record in support and had taken actions needed to accomplish the demonstration program.
- Much of the technology was mature. This was predominantly engineering manufacturing development, not science and technology. While there was significant technical risk—which was why the demonstration was proposed—this was not a situation in which core technologies had not yet been developed.
- There was a credible plan for transition of DARPA-sponsored technology to an operational user. The Air Force, which was likely to have responsibility for deployment and operation of a space-based radar, was a partner.

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43 RDT&E Budget Item Justification Sheet (R-2 Exhibit). Budget Activity 05-Engineering and Manufacturing Development. PE 0604251F, "Space-Based RADAR EMD," June 2001.

44 *Space-Based Radar (SBR)*.

45 RDT&E Budget Item Justification Sheet (R-2 Exhibit). Budget Activity 05-Engineering and Manufacturing Development. PE 0604251F. *Space-Based RADAR EMD*. June 2001.

46 *Space Based Radar (SBR) Meeting with Industry*, FBODaily.com., FBO #0034, January 5, 2002.

47 Vernon Loeb, "New Weapon Systems are Budget Winners," *The Washington Post,* February 8, 2002, p. A29.

- There was support from Combatant Commanders. Space Command was on record that DII was a high priority.
- Significant improvements in operational capabilities were expected, due to near-continuous, deep GMTI and level 5 DTED information to support precision targeting (with theater commanders able to task the system and directly receive data).
- Fierce initial opposition to the lightsat concept had largely been overcome. Most parties involved in the deliberations appeared prepared to address what kind of lightsat might be appropriate for a specific set of missions.

Much of the reporting concerning DII focused on cost considerations, both for the demonstration, which was intrinsically expensive because it required space launch of two systems, and for the follow-on constellation that might be deployed given a successful demonstration. The story in large part was one in which the House appropriators opposed DII largely because of the program's perceived expense, while it was supported by Senate appropriators and by authorizers in both chambers.[48] However, while cost most certainly was an important consideration, it appears to have been a necessary but not sufficient cause for the outcome.

It was not the case that three committees supported DII and the House Appropriations Committee opposed. As explicated in the authorization language quoted previously, the authorizing committees supported only a portion of the program, with emphasis on such matters as operational requirements and concepts and a formal analysis of alternatives to show the specific contributions that a space-based radar would make in the ensemble of systems that would support achievement of GMTI and DTED objectives. These concerns had been foreshadowed in external reviews. The Jeremiah Panel noted that:

> The exact implications of this vision of future military ISR needs for space reconnaissance are not totally clear because of uncertainties at this point over the relative roles of airborne reconnaissance systems, nonintelligence space surveillance systems, and space reconnaissance systems.[49]

A formal analysis of alternatives with departmentwide participation had not been conducted to show and prioritize the unique additions to capability that would result if DII was deployed.

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48 For example, the summary provided in James T. Hackett, "Keeping Our Lead in Space," *Washington Times,* June 23, 2000.

49 *Defining the Future of the NRO for the 21st Century*, p. 8.

The DSB Task Force on Satellite Reconnaissance concluded its appraisal with the following statement:

> The Joint Staff should continue to develop its system decision process for these mission areas. The Task Force was impressed with the progress reported by J8 in developing a decision for surveillance and reconnaissance capabilities that engaged the system developers, Services, and CINC staffs. The success achieved with the Space Based Infrared (SBIR) System decision and the process projected for FIA using the Senior Warfighters Forum is impressive. In our view, forcing the operational users and the system advocates into the same venue where resource constraints and military value can be evaluated together is a superior way to make the necessary trades for the Nation...[50]

While DII did have expressions of support from the Air Force and Space Command, a formal Mission Need Statement had not been completed. Nor had a formal joint requirements assessment (possibly to include a Capstone Requirements Document) been accomplished. Hence, those advocating the program could point to expressions of need, but could not cite a formally developed and validated joint military requirement.

A related consideration, addressed in none of the public documentation reviewed, is the absence of what might be considered an obvious participant: the National Imagery and Mapping Agency (NIMA). This intelligence community organization's mission involves the DTED level 5 geolocation data proposed as one of the primary products to be collected using DII. NIMA endorsement and participation, particularly if based on a formal analysis of alternatives and following a formal requirements/mission needs process, might have had an impact on the decision. Possibly due to the absence of NIMA as a partner, much consideration of DII focused on GMTI, some of which could be gathered by JSTARS or other non-satellite systems, as opposed to DTED level 5 data that would be provided by DII.

Since cost was necessarily a consideration for an expensive demonstration, the fact that the Air Force appeared to have difficulty finding the funds needed for the demonstration and attempted to use S&T dollars for what had previously been supported with engineering manufacturing development resources worked against success. Given these difficulties, an external observer, in Congress or elsewhere, might legitimately begin to question the funding stability of the program.

The extent to which the three partners were able to make arguments in support of DII, given the other matters that also had to be addressed in their interactions with Congress, also may have been an issue. Illustrative is testimony by Director, DARPA in 1999. The importance of

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50 *Defense Science Board Task Force on Satellite Reconnaissance*, p. 7.

DII is emphasized in this statement. However, many other programs are also addressed, and the primary presentation for DII (on p.14 of the prepared statement) involves less than one-half page in a 33-page document.[51]

A similar point holds for senior-level advocacy in support of DII. As noted previously, the Secretary of Defense wrote to congressional appropriators in support of the program. However, this support was in the context of a letter that addressed multiple programs and considerations.

A related observation applies for some of the external advocacy. A case in point is the Air Force Association, which supported continued funding of DII development, subject to the condition that *Discoverer II funding not be taken from unmanned aerial vehicle options*.[52] This is support that directs attention to funding issues and to the absence of an analysis of alternatives to develop a validated mix of satellites, aircraft, and UAVs for the DII missions. Read literally, the AFA statement implies that UAVs should be a higher priority than DII.

Furthermore, some shadows from the past remained. One of the appropriators' concerns was the impact that a DII constellation would have on an already overtaxed imagery processing, exploitation, and dissemination system. This is a national capability of the type with which the NRO FIA must interface. The concept for DII did not involve this national capability; instead, the proposed interface was direct-to-theater, one of the specific selling points for the system. From this comment, it is clear that DII had not been completely distinguished from national imagery systems. Had NIMA been a partner in the demonstration, it might have been possible to alleviate such concerns.

LOOKING TO THE FUTURE

What should DARPA (and partners) do differently in situations in which technology enables truly revolutionary improvements in military capabilities, but the development of these technologies requires an inherently expensive program? Two points for consideration involve 1) requirements processes, and 2) advocacy.

As part of the continuing evolution and implementation of the Goldwater-Nichols framework, the Joint Staff has continued to refine the system requirements process to ensure that it responds to priority CINC requirements. One of the key problems for DII was the absence of

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51 Frank Fernandez, Director, Defense Advanced Research Projects Agency, Statement Before the Subcommittee on Emerging Threats and Capabilities, Committee on Armed Services, United States Senate, April 20, 1999.

52 *2001 Force Capabilities Issue Paper – Information Dominance*, Arlington, VA: Air Force Association, 2001.

supporting documentation from this process, e.g., an analysis of alternatives and mission need statement.

One possibility would be for DARPA to increase its participation in these processes. This would make it more likely that new technological options are given consideration in requirements appraisals. It would also increase the requirements documentation available in support of DARPA proposals. The issue here is practicality, given the amount of time this would involve. DARPA is deliberately managed as a lean operation with short-tenure program staff. There are not enough people with enough hours in the day to do this while managing current programs. Furthermore, some short-tenure staff may not have the knowledge and experience needed for maximum effectiveness in such fora. A more practical option might be instituting a more formal relationship between the Joint Staff and DARPA for matters involving interfaces between next generation technologies and the requirements process directed at achieving next generation systems. Small liaison organizations with DARPA and J-8 might assist in coordination.

The second longer-term issue involves advocacy. When dealing with an inherently expensive program—a demonstration phase of almost a billion dollars (including space launch), plus major costs for an eventual system deployment—how is the DoD case best presented? At these magnitudes, DARPA advocacy may be necessary but not sufficient. There are significant precedents. It was expensive to develop, demonstrate, and deploy the first ICBMs and SLBMs. The same was true for the Discoverer/Corona satellites.

In the past, however, the primary advocate for the enabling S&T investments was the DDR&E, who was a more senior official within the department. For investments at this scale in terms of immediate and longer-term costs, comparable level advocacy may be needed today and in the future. This would involve more than involvement of USD(AT&L), though this would be needed. It would also require a corporate decision by the department that the program is a department priority, as opposed to an agency- or service-level initiative.

The history of DII highlights the difficulty of performing inherently expensive demonstrations of disruptive capabilities that cross traditional organizational boundaries. The high cost invited demands to link the capability to specific requirements and pursue it like an ordinary system acquisition. This was difficult to do for a disruptive capability that addressed needs in a new way, as there was not a large base of experience from which to draw. And because organizational boundaries were being crossed, competition for missions clouded the process. With the current administration's focus on space-based capabilities, a more forceful imprimatur may evolve for capabilities like DII.

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Appendix

DEFENSE SCIENCE BOARD TASK FORCE ON SATELLITE RECONNAISSANCE DEFENSE SCIENCE BOARD

WASHINGTON, DC

JAN 1998

Introduction

The National Reconnaissance Office (NRO) is in the process of creating a Future Imagery Architecture (FIA) as a basis for acquiring the next generation of imaging satellite systems and their associated ground control and processing. At the same time, Defense Advanced research Projects Agency (DARPA) is advocating demonstrating a space radar surveillance system (Starlite) incorporating advanced and higher risk technologies with cost and performance attributes that could have future application to the FIA. The Directors of DARPA and NRO have asked that a Defense Science Board (DSB) Task Force be established to review the operational, technical, industrial and financial aspects of each of these initiatives and recommend a course of action for the Department.

The Task Force membership is shown in Appendix B. It includes six members that also served on the Small Satellite Group convened by the Director of Central Intelligence in 1996 to review FIA approaches and alternatives.

The Task Force received a series of briefings from DARPA, NRO, National Imagery and Mapping Agency (NIMA), Air Force, and the Joint Staff. These briefings addressed plans for both sets of systems, the state of requirements definition, and the status of the existing inventory. The issues raised involve resource decisions, military operational concept choices and matters of roles and missions of the Military Departments and several agencies.

How the Players See the Issues

While the following viewpoints were not explicitly presented to the Task Force, we believe they reasonably represent important viewpoints and also define the fundamental issues that need resolution.

An NRO Point of View

The NRO is developing, acquiring and operating Satellite Reconnaissance Systems that respond to the needs expressed by the DCI, the Secretary of Defense, the National customer, and the warfighter customer. The NRO is supporting the research and development necessary to achieve that objective. These systems are critical to the security of the US. Hundreds of decision makers and thousands of analysts depend on their product. The current inventory of imaging satellites has a finite life and the next generation is needed to assure the continued availability of essential products. The NRO has conducted extensive trade-off studies to define the architecture of the next generation system, its system attributes and the process by which it will be acquired. An elaborate process is in use for the government to define requirements to be satisfied by the new set of systems. This process has matured to the point of an approved draft statement of requirements. The acquisition process is well on its way to definition. The NRO believes the result is an objective architecture as modern and enlightened as the Department of Defense has ever undertaken.

The NRO is in the middle of a demanding task, already strained in resources and schedule and the proposal by DARPA to design and build a radar satellite system could be seen as troublesome in several aspects:

- The proposal could be perceived as competing with a segment of the FIA without any reference to the requirements rigor associated with the FIA program or a defined relationship with the rest of the FIA system. Further, the Starlite approach is higher risk than NRO considers prudent given the need for continuity in providing needed reconnaissance products. The Director of DARPA has stated clearly it is not in competition since Starlite is on a riskier and longer term path.
- This perception of competition is complicated by a potential future conflict between the role of the NRO and Air Force plans for future migration of key surveillance and reconnaissance capabilities from aircraft to spacecraft. The image of satellite based JSTARS and AWACS are projected as examples. The Starlite program has been presented as a candidate approach to meeting some future mission needs with emphasis on an “operational” vice “intelligence” role. With this formulation, it is likely that the Air Force would expect to be the follow on procurement agency after a successful demonstration.
- Starlite appears to need several hundred million for a two satellite demonstration. The NRO fears that they might be the bill payer although they are already short of the amount they think will be required to put FIA in place on the required schedule.

A DARPA Point of View

DARPA has a responsibility to introduce advanced technologies, techniques and concepts into the Department's process for creating armed forces. It has done so for decades with notable successes to their credit. Up to now, there has been little or no DARPA involvement in the satellite reconnaissance business since NRO has been regarded as the cradle-to-grave custodian of that segment of the Department's business to include pushing the kind of innovation that has characterized DARPA's contributions to other force capabilities. DARPA sees, that as NRO has matured and become more focused on evolutionary improvements to satisfy their customers, there is a need for the DARPA approach to help introduce more revolutionary (and higher risk) technologies and concepts. The technologies incorporated in the Starlite program makes it high risk and an on-orbit demonstration of the capabilities is part of the necessary risk reduction.

In particular, Starlite has the potential to demonstrate several important attributes:

- The operational value of nearly continuous access. Precision weapons require precision sensors to support their potential leverage. The availability of nearly continuous, precise and rapidly reported target information would provide for a major advance in military operations and support the US objectives of information and battlefield dominance.
- Reduced cost of ownership. By exploiting emerging technologies and the industrial process in place or being created, DARPA believes it can design and demonstrate system capabilities to provide nearly continuous access at an affordable cost.
- Easier access by combat units. DARPA believes that by using direct downlink access to combat units without security classification constraints, a potential revolution in capability can be achieved.
- Enabling International cooperation. The unclassified, operational attributes of a systems such as Starlite would be a useful vehicle for engaging Allies in cooperating in satellite reconnaissance. Depending upon one's view of this prospect, it could provide both resource and political leverage for the United States.

Part of DARPA's responsibility is to put forward new technologies and concepts where they see high value added potential. Starlite is representative of the revolutionary programs that DARPA has moved forward in the past with great success and the potential of this approach should not be bureaucratically constrained.

An Air Force Point of View

The Air Force has recently made a corporate judgment that important surveillance and reconnaissance functions which it now addressees in its Title X responsibilities to organize, equip and train Air Forces should be migrated to spacecraft. The family of current and planned aircraft systems that address these needs have significant limitations that can be addressed by migrating some of these capabilities to satellite systems.

The Air Force believes that as these missions are migrated to spacecraft they will be responsible for acquisition and operation of these systems. While it recognizes that the satellite as a military sensor evolved from use in intelligence activities, the maturity of the technologies and the evolution of precision, remotely operated weaponry dictates that space sensors now become fully integrated into the operational military systems and culture.

Starlite promises significant characteristics of what the Air Force considers to be needed in an operational system. It provides near continuous access, direct and timely reporting for the purposes of supporting targeting, and freedom from burdensome intelligence community security classifications and handling procedures. It can be very much like a JSTARS in operational concept without the range and shadowing problems and without the operational and logistics footprint of a multi-aircraft system.

Task Force Assessment

There is merit in each of the three viewpoints described. The following presents the Task Force perspective and set of recommended actions that we believe accounts for the merit in each of the preceding viewpoints and that can help avoid the expense and bureaucratic acrimony that might result if they are not treated carefully.

The major conclusions of the Task Force are:

1. FIA Must Proceed on Schedule With Next Generation Systems.

   The FIA program and the process that produced it will provide improved capabilities while balancing cost, risk and performance for achieving the next generation of space systems. Its development is integrated into the Department of Defense decision process and the transparency of its creation is as complete as ever achieved for an NRO system. Its schedule is already strained and should not be subjected to the substantially increased risks associated with the Starlite system.

   FIA program decisions should be decoupled from Starlite program decisions. FIA comes from a mature process that must provide a high confidence path to providing for identified needs of the Nation and the Department. Starlite is a much more speculative proposal involving questions of technical risk, product value and cost. It should be judged on its own merit as an advanced technology program. It is higher risk than is appropriate for the next generation systems that will make up FIA and is not competitive with the next generation FIA.

2. The Starlite System Objectives Are Important for Military Operations.

   The Task Force believes the objectives of Starlite are an appropriate basis for substantial investment. We believe that future military operations will need the combination of day, night and all-weather access, the rapid revisit of imagery and broad-area, moving-target surveillance represented by this proposal.

   We agree that achieving these objectives is best achieved through the proliferation of low-orbit satellites. We also agree that, of necessity, they must and can be greatly reduced in cost from past practices. Finally, we agree that major effort and design is needed to integrate these space systems into military force structures, weapons systems and on-going military operations.

3. FIA Should Be Open to Some Starlite Attributes.

   The FIA should accommodate some of the attributes emphasized in the Starlite proposal. In particular;

   - Increased consideration should be given to achieving Moving Target Indicator (MTI) and rapid revisit image coverage on an evolutionary schedule.
   - The fact of FIA systems should be unclassified and their essential operating characteristics should be held no higher than SECRET. There may become aspects of each program that should be more closely held but that is achievable without incurring the hindrance to operations imposed by the strong propensity for excessive classification. The data output from FIA should be at SECRET classification or lower consistent with policy makers' and users' needs to protect knowledge of what is being imaged.
   - NIMA, MRO, The Military Departments and the Joint Staff should focus particular attention on integrating FIA systems with military operations. It is our judgment that a formal program that addresses operational concepts, system architecture modifications, and the application of new technologies should be organized. An important aspect of such a program will need to be education, training and exercise participation

4. A Modified Starlite Program Should be Initiated.

   The Task Force recommends that the Department of Defense undertake a program to create a Military Space Radar Surveillance Program targeted to achieve broad-area, all-weather and near continuous radar access for integration with military operations. We recommend that this program proceed with the following considerations:

   - The program should be designed to bring leading edge, higher risk, technologies to provide needed capabilities (sensing, processing, distribution) to meet warfighters' needs at lower cost. Accordingly, a technical risk reduction program should be planned and executed. The program should make appropriate use of existing and planned space systems, airborne systems and laboratory investigation. An on-orbit demonstration system is likely to be needed to complete the risk reduction program but, there are significant risk reduction efforts that need to precede the on-orbit system so that the system definition is more mature and can lead more directly to an operational prototype.

- The primary purpose of this system would be to support on-going military operations and its design must emphasize integration with combat force systems. The Task Force believes this argues for an eventual acquisition, organization and training role for the Air Force under its normal Title X responsibilities. Likewise, DARPA should be expected to play its normal role as a source of innovation in military system capabilities. The NRO will need to participate during this transition phase because of its historical role, its access to space reconnaissance systems competence and the operational interaction between NRO systems application and this new military system.

5. The Future Roles and Relationships of Defense Organizations Need to Evolve for These Missions.

The Task Force believes that much of the intensity of differences involved in this issue can be traced to the structural deficiencies in the assignment and execution of roles and missions in this increasingly important area of intelligence, reconnaissance and surveillance in support of military operations.

We believe that adjustments must be made to avoid continuing and debilitating struggles for turf for the foreseeable future. Accordingly, the Task Force offers the following recommendations:

- The NRO should continue as the acquiring and operating organization for satellite sensor systems that are acquired primarily for intelligence and strategic reconnaissance purposes. These systems will naturally migrate to increasing attributes of real-time and precision and will have very important capabilities for supporting military operations. These capabilities should be exploited fully in support of military operations as priorities demand. This calls for increasingly close cooperation between the NRO and the Military Departments in serving the Warfighter's needs as these systems evolve.

- The Military Departments should transition to an increased role in space sensor systems that are acquired primarily for the purpose of support to on-going military operations and there is a premium for integration with other weapon systems and military force operations. We believe the Air Force is the logical Department to accept Title X responsibility for the Military Space Radar Surveillance Program after DARPA has brought the technologies to an acceptable level of risk. These systems will inevitably have attributes that will be very important to the intelligence agencies of the Nation. These systems should also be exploited to serve intelligence needs. Close cooperation between the Military Departments and the NRO is needed to ensure the highest return from development efforts and operational employment.

- The Secretary of Defense and the Director of Central Intelligence will need to give special attention to preventing unnecessary redundancy and exploiting the complementary value of the systems created in response to these differing motivations.

- DARPA should continue to press innovation, and advanced technologies, techniques and concepts into the Department's process for creating armed forces in this area as it has done for decades in many other areas with notable success. The objectives outlined for Starlite are worthy of their attention and investment. The Task Force believes it would be appropriate for DARPA to take the lead responsibility for the risk reduction phase of the Military Space Radar System Program. We also believe that DARPA has much to offer in the processing and exploitation segment of these mission areas.

- NIMA must increase its ability to assure effective integration of operational and intelligence oriented space and airborne imagery systems. Since all of these systems will have some similar characteristics and will be capable of multiple applications, there is increased danger of real and apparent overlap and duplication of resources as well as unwarranted restriction of use. It is imperative that NIMA perform its role of rationalizing needs, creating systems and procedures for processing and exploitation, and insuring their proper application to multiple purposes.

- The Joint Staff should continue to develop its system decision process for these mission areas. The Task Force was impressed with the progress reported by J8 in developing a decision for surveillance and reconnaissance capabilities that engaged the system developers, Services, and CINC staffs. The success achieved with the Space Based Infrared (SBIR) System decision and the progress projected for FIA using the Senior Warfighters Forum is impressive. In our view, forcing the operational users and the system advocates into the same venue where resource constraints and military value can be evaluated together is a superior way to make the necessary trades for the Nation.

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During the 1970s, 1980s, and 1990s, DARPA managers supported the development and deployment of novel combinations of advanced technological systems and original operational concepts that "disrupted" existing methods of conventional warfare. These disruptive military capabilities helped the US Department of Defense significantly enhance its conventional warfighting superiority by fostering a broad transformation commonly known as the "Revolution in Military Affairs," or RMA, which played to US national technology strengths. Examination of several cases in the domains of stealth, standoff precision strike, and ISR (intelligence, surveillance and reconnaissance) highlights DARPA management practices that facilitated the conception, development, acquisition, and deployment of these disruptive capabilities.

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