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Transformation and Transition: DARPA's Role in Fostering an Emerging Revolution in Military Affairs
Volume 1 – Overall Assessment

Richard H. Van Atta, Project Leader
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PREFACE

This report summarizes work performed by the Institute for Defense Analyses for the Director of the Defense Advanced Research Projects Agency (DARPA), in partial fulfillment of the task entitled "DARPA's Role in Fostering a Revolution in Military Affairs (RMA)." It highlights the roles DARPA has played since the 1970s in developing and exploiting advanced technological systems to create fundamental warfighting advantages for US military forces.

The study's results and conclusions are contained in two volumes. Volume I, *Overall Assessment*, provides an overview of several DARPA program areas studied as part of this task and from these draws insights and "lessons learned" for DARPA management. Volume II, *Detailed Assessments*, documents the DARPA program areas with greater specificity.

The authors wish to thank John Jennings of DARPA; Kent Carson of IDA; and Larry Lynn, former DARPA director, for their detailed review of prior drafts. The authors also benefited from access to past DARPA and US Department of Defense (DoD) leaders, who gave generously of their time and provided insights on problems and opportunities for DoD in developing and deploying novel capabilities. We wish to thank Joe Braddock, Malcolm Currie, Robert Fossum, George Heilmeier, Steven Lukasik, Robert Moore, William Perry, Henry Rowen, James Tegnelia, and numerous others. Of course, the conclusions of this study and any errors in representation of history are the sole responsibility of the authors and do not necessarily represent the views of these contributors, the formal reviewers, or current DARPA or DoD management.

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INTRODUCTION: 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, DARPA on occasion 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 a disruptive capability. 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 describes how certain DARPA-sponsored systems and demonstrations since the 1970s contributed to the development of disruptive capabilities in the areas of stealth, standoff precision strike, and advanced ISR and hence to an emerging RMA. (It does not assess in detail DARPA's role in supporting development of generic technologies—most notably microelectronics, computing, networking, and other information technologies—that underlie these and other emerging disruptive capabilities.) It highlights management practices that facilitated the development and exploitation of these disruptive capabilities, specifically:

- Investing in basic technologies that can lead to fundamental technical advantages
- Building communities of change-state advocates

- Defining strategic challenges in detail across multiple scenarios
- Supporting the conceptual development of integrated, disruptive capabilities
- Testing promising disruptive capabilities in large-scale, proof-of-concept demonstrations
- Working with leadership from the Office of the Secretary of Defense (OSD) to broker Service commitment to the implementation of particular disruptive capabilities

CONCEIVING DISRUPTIVE CAPABILITIES

DARPA's contributions to the emerging RMA occurred in the context of a clear imperative at the end of the Vietnam War: defense of Western Europe. Warsaw Pact offensive forces in Europe had been significantly increased and improved. Soviet-designed integrated anti-aircraft systems were very effective against US-built jets in Vietnam and in the 1973 Yom Kippur War. And the Soviet Union had achieved rough parity in nuclear weaponry. Taken together, these changes undermined the North Atlantic Treaty Organization's (NATO) defensive plans, which depended on using theater nuclear weapons and fighter jets to blunt the advance of numerically superior Warsaw Pact ground forces. (It was not deemed practical to increase NATO conventional military procurement and manpower to match Warsaw Pact numbers.)

Sustained concept development studies, funded in part by DARPA, defined the challenge in detail across multiple scenarios and conceived alternative technical and systems responses. *The key idea that came out of these studies was that precision conventional weapons with survivable delivery systems would allow NATO to counter Warsaw Pact ground forces without using nuclear weapons.* During the same period, DARPA was reorganized with the aim of making it more effective in addressing military needs. It built relationships with potential Service users and operating commands and consolidated several programs into outcome-oriented thrust areas. In the late 1970s, some of DARPA's thrust areas were incorporated by Secretary of Defense Harold Brown and Under Secretary William Perry into a broad defense strategy known as the "Offset Strategy." The Offset Strategy held that synergistic application of improved technologies and novel military systems for standoff precision strike from survivable platforms would allow the US to counter Warsaw Pact forces. With the Secretary of Defense's imprimatur, several DARPA technologies and systems concepts were moved from idea to implementation.

IMPLEMENTING DISRUPTIVE CAPABILITIES

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.

Stealth Combat Aircraft

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 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 quarter-scale HAVE BLUE aircraft to test out stealth concepts while meeting limited but realistic operational requirements. Successful flights of the HAVE BLUE planes persuaded Under Secretary 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 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.

Standoff Precision Strike: Air Force and Army

DARPA's Robert Moore was briefed on the 1970s DARPA-sponsored concept development studies described earlier that defined alternatives for defeating massed Soviet armor using precision guided conventional weapons rather than nuclear weapons. By combining several ideas from different sources, he 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.

Naval Stealth and Standoff Precision Strike

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). On April 29, 2002, Northrop Grumman Ship Systems was selected as the lead design agent for DD(X).

Intelligence, Surveillance, and Reconnaissance

ISR systems interconnect several interdependent subsystems including:

- *Sensors,* to detect and monitor enemy and friendly forces
- *Platforms,* to deploy sensors
- *Processing,* to convert sensor data into coherent information and visualizations
- *Fusion,* to provide integrated knowledge and intelligence at different levels of detail

- *Communications links,* for dissemination of information and knowledge

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

Two 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: Praerie 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 built Condor, but it failed to gain support for production. The Army's Aquila Program emerged from the initial DARPA-Army collaboration on Praerie. 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). 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 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; 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 Undersecretary 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 allow DARPA to 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 cancelled due to flight test failures and budget overruns. The Predator (Tier II) was delivered for user experimentation in just 6 months using the newly created 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.

Space-based Radar

A 1997 DARPA-sponsored study proposed developing an experimental space-based radar, founded on DARPA technologies, that 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.

CONCLUSIONS

Insights from the Reviewed DARPA Programs

DARPA has been instrumental in the development of a number of technologies, systems, and concepts critical to the RMA. It did so by serving as DoD's corporate research activity, reporting to the top of the organization, with the flexibility to move rapidly into new areas and explore opportunities that held the potential of "changing the business." DARPA acted as a catalyst for innovation by defining research programs linked to DoD strategic needs, seeding and coordinating external research communities, and funding large-scale demonstrations of disruptive concepts. In doing so, the DARPA programs described in this study presented senior DoD leadership with opportunities to develop disruptive capabilities. With consistent senior leadership support, typically from the highest levels of the Office of the Secretary of Defense and the Services, development of disruptive capabilities transitioned into acquisition and deployment. Otherwise, only the less disruptive elements moved forward. Disruptive concepts also tended to progress further if they:

- Were focused on a small set of clear, high priority missions
- Did not compete directly with the missions of existing large platforms
- Involved only a single Service
- Did not require multiple contractors for integration
- Could be run as classified programs
- Could be brought to an acquisition decision during the tenure of the initial high-level decision makers.

To illustrate, Table S-1 compares the F-117A, UAVs, and ASSAULT BREAKER along these dimensions. The text below elaborates on these observations in these cases and in the others described in this study.

Table S-1. Comparison of F-117A, UAVs and ASSAULT BREAKER

	F-117A	UAVs	Assault Breaker
Mission Clarity	Relatively focused, high-priority mission	Multiple missions, ops. concepts & tech. needs	Change in mission need during development
Mission Competition	Focused on missions that existing aircraft could not perform	Overlapped large platform missions	Substitute for a core mission of large platforms
Jointness	Attached to single platform owned by individual service	Multiple platforms but single-service deployment	Intrinsically joint, requiring major changes in doctrine
Integration	District platform implemented sole-source	Multiple platforms but single contractor for each	Multiple contractors for each "system of systems" component
Openness	Secret and "black" (compartmentalized)	Mixed secret/black and open	Open
Timing	Brought to acq. decision during a single administration	Successful transition once top-level imprimatur given	Demonstration completed after initial decisionmakers gone

In championing stealth, DARPA harnessed industry ideas and funded the considerable engineering work required to enable top OSD and Service leadership to proceed with confidence with a full-scale acquisition program. OSD leadership kept the F-117A program focused on a limited set of high priority missions that existing aircraft could not perform well, with a target completion date within the same administration. OSD leadership kept the program classified and worked with Congress to protect its budget. The result was a "secret weapon" capability—exactly what DARPA and top DoD leadership had envisioned.

DARPA played a similar instigating role to develop and prove disruptive surface ship concepts, based in part on the same stealth technology as the F-117A. Proof-of-concept ships such as Sea Shadow were built, but, without a strong impetus for change, consistent high-level imprimatur, and a focused mission distinct from those performed by existing ships, the Navy has not fully developed or acquired the envisioned disruptive capability.

In the case of standoff precision strike in the Army and Air Force, DARPA worked for years on systems for finding, hitting, and destroying targets on the battlefield under a variety of conditions, and then demonstrated how a particular "system of systems"—ASSAULT BREAKER—could yield a disruptive capability. The ASSAULT BREAKER concept, in addition to being intrinsically joint, challenged the core mission of several large platforms, and required multiple contractors. Furthermore, with the collapse of the Soviet Union, the intended mission of defeating Soviet echeloned forces disappeared. As a result, individual elements of ASSAULT BREAKER have been fielded, but only in modified forms that constitute less joint and less disruptive capabilities. Terminally guided submunitions and subsequent "smart weapons" have yet to be deployed.

Finally, in the case of UAVs and Discoverer II, DARPA sought to exploit ISR investments that had been a core area of DARPA research since its inception, yielding a broad range of component and subsystem breakthroughs. In particular, they sought to bring control of ISR capabilities to tactical users. In the early years, UAV developments were often caught in a death spiral, in which unrealistic initial performance requirements led to increasing complexity, which led to high costs and development difficulties, which reinforced the idea that UAVs could not affordably meet requirements. With top leadership attention and strong limits on the escalation of requirements (by taking programs outside the normal acquisition system), Predator and Global Hawk were successfully developed and employed in combat, despite being only experimental systems. However, Discoverer II's high cost and the failure of OSD and Service leadership to address perceived mission overlaps led to imposition of standard acquisition requirements, which, as a demonstration system, it could not meet.

Management Lessons: Vision and Leadership

Achieving transformation via implementation of disruptive capabilities requires both *vision* and *leadership*. Vision, the primary role of DARPA management, involves conceiving, developing, and demonstrating disruptive capabilities. Leadership, the primary role of DoD management above DARPA—the Director of Defense Research and Engineering, the Under Secretary of Defense for Acquisition, Technology and Logistics, and the Secretary of Defense—involves moving demonstrated disruptive capabilities into acquisition and deployment.

Vision: DARPA Conception, Development, and Demonstration of Disruptive Capabilities

DARPA's higher-risk, longer-term R&D agenda distinguishes it from other sources of defense R&D funding. Perhaps the most important effect of DARPA's work is to change people's minds as to what is possible. The following management practices, when employed by DARPA, can promote the conception and development of disruptive capabilities.

- Investing in basic technologies that can lead to fundamental technical advantages

DARPA's steady, forward-looking promotion of critical technologies—before their national security significance becomes clear—has supported US dominance of entirely new industries, e.g., microelectronics, advanced computing, networking, and other information technology industries that underlie many of the military systems capabilities associated with the RMA. DARPA's ability to support technologies that are not tied to formal military requirements distinguishes it from Service labs.

- Building communities of change-state advocates

Beyond technology investments, DARPA often acts as a leader and catalyst for cross-fertilization among forward-thinking academic researchers, military operational experts, and private industry. Building such relationships encourages the conception and development of disruptive capabilities by facilitating the exploration of novel ways to apply technology to military problems. The process begins internally, with the recruitment and hiring of high quality program managers from government, industry, and academia who have innovative ideas that they are eager to make real. Once a concept is proven, the Services may be more willing to support the next phase of development.

- Defining strategic challenges in detail across multiple scenarios

DARPA has sponsored study efforts to define and articulate fundamental, strategic challenges that faced US forces in multiple potential battle scenarios. The results of these studies helped DARPA leadership set research priorities and communicate them to program managers, overseers, and contractors.

- Developing disruptive systems concepts

Based on well-defined strategic challenges, DARPA has conceived novel integrated concepts linking technical capabilities with defense missions, breaking Service-specific paradigms. The articulation of disruptive concepts helped create a "critical mass" of research effort around them.

- Testing promising disruptive concepts through large-scale, integrated demonstrations

DARPA's demonstrations of large-scale, high-risk disruptive concepts convinced DoD leadership, Congress, and the Services of the potential value of new approaches.

A fundamental tension for DARPA is balancing its pursuit of high-risk research independent of a defined need with its demonstration of capabilities that address a specific strategic problem (but not defined requirements). Although integration projects may be just as "high risk" as research projects, philosophically, culturally, and managerially, these are very different processes. The DARPA Director needs to mediate between these missions and, more importantly, bridge the two communities. DARPA was effective in the cases covered here in part because a strong axis between DARPA and top OSD leadership formed around ambitious outcomes, not technologies per se. An outcome orientation is particularly important in explaining DARPA programs to Congress.

Leadership: Acquisition and Deployment of Disruptive Capabilities

The case studies make this clear: *If fielded disruptive capabilities are the objective, it is insufficient for DARPA to create an example and then rely upon the traditional Service acquisition system to recognize its worth and implement it.* Because acquisition and deployment of disruptive capabilities challenge existing programs and bureaucracies, it is difficult to find eager Service customers for them. Also, because new capabilities are not technically mature or operationally robust, the Services will generally be reluctant to take on the significant and potentially costly risk reduction efforts required to move them into acquisition.

Hence, rapid acquisition and deployment of disruptive capabilities requires an integrated and consistent senior leadership effort, typically from the Director of Defense Research and Engineering or the Under Secretary for Acquisition, Technology and Logistics. OSD leaders must also have allies among top Service leadership in order to alter the course of ordinary organizational politics, and they must often exercise their authority to overcome the resistance of people to new ideas and of organizations to uncertainty, risk, and perceived competition. In the cases reviewed in this report, the following types of actions facilitated the transition of disruptive capabilities:

- Brokering deals with Service leadership

OSD leadership worked with Service leadership to build internal champions for new operational concepts and to secure and sustain the budgetary and operational resources required for acquisition and deployment of disruptive capabilities.

- Creating an independent organization within a Service or in an outside agency

To create an organizational home for development, one successful approach has been to seek out forward-thinking officers to staff an independent organization within the Service to develop and field the new capability. (In addition to facilitating development, the formation of new organizations can create a career path for innovative military officers.) When a disruptive concept is inherently joint and cannot be attached to a platform that a single Service owns, an alternative is to create a new organization independent of the Services. Predator and Global Hawk were successfully developed as experimental systems in this manner.

- Working with Congress to protect funding

OSD and Service leadership must work with Congress to ensure that funding for disruptive capabilities is protected in budget competitions with traditional programs.

- Providing a clear, top-level imprimatur for risk reduction and acquisition of specific capabilities

Top DoD leadership support can be instrumental in addressing acquisition issues involved in bringing immature technology and systems to fruition. An "incubator model" is often used, in which a new capability is initially focused on a highly specific and limited application area and then iteratively enhanced through experimentation with gradually more challenging missions until it is sufficiently mature, reliable, and supportable to meet the demands of acquisition, testing, and evaluation organizations. Once sufficient risk reduction has been achieved, DoD programs and initiatives designed to encourage transition of disruptive concepts, such as Advanced Concept Technology Demonstrations (ACTDs), Battle Laboratories, and Joint Forces Command (JFCOM) experimentation efforts, may be applied. At that point, DoD leadership may again be required to move the resulting capability into a Service or joint acquisition organization.

Looking to the Future

It is very difficult to achieve disruptive changes when the US military is felt to be very capable and successful. It will be a challenge for DoD to develop and implement disruptive capabilities without the type of clear, strategic imperative that drove the developments outlined in this report. In order to inspire action, the strategic challenges facing the US must be clearly delineated in sufficient detail to inform research and development priorities, and senior DoD leadership must create an environment that is supportive of new integrated concepts, true experimentation, learning, and adaptation. Guided by an understanding of evolving defense needs and emerging technologies, DARPA and OSD need to formulate an agenda—fusing high-level policy, technology, and operational concerns—for the development of the disruptive capabilities that will provide the US strategic competitive advantages in the future, putting the US at the forefront of future RMAs.

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I. INTRODUCTION

A. Overview of DARPA

The Defense Advanced Research Projects Agency (DARPA)[1] was established in 1958 in the wake of the Soviet launching of Sputnik. Its primary mission is to foster advanced technologies and systems that create fundamental, "revolutionary" advantages for the US military. DARPA does not perform research directly but rather conceives and finances projects, serving as an active broker among technology, military, and occasionally policy communities. Consistent with its mission, DARPA pursues a portfolio of research and development (R&D) projects at different levels of risk and of different scale in a large variety of technical fields. Internally, DARPA maintains a small, flat, agile organization. Under the director are a deputy, directors and deputy directors for its half dozen or so standing offices, and individual program managers (PMs). DARPA's culture encourages taking risks and tolerates failure.

By design, DARPA is independent of Service R&D organizations. But it is nonetheless embedded in a complex set of relationships. It receives from Congress a budget which it distributes with oversight and policy direction from top DoD civilian officials. When DARPA was created, it reported to the Secretary of Defense and was assigned projects by the White House. Today, the DARPA Director reports to the Director of Defense Research and Engineering (DDR&E), who reports to the Under Secretary of Defense for Acquisition, Technology and Logistics, who reports to the Secretary of Defense.

DARPA PMs drive its research portfolio. They are encouraged to challenge traditional thinking and approaches to national security problems and to be outcome oriented, looking for results rather than just exploring ideas out of general interest. It is common for a DARPA PM to be a researcher who has experienced frustration in gaining support in a "home" organization, has a broader technical interest and more long-term focus than a Service would likely support, or is interested in technology areas that are not the mainstay of existing Service programs. To help DARPA attract top technical talent outside government, and to encourage a steady stream through the agency of new PMs

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1 DARPA was originally called ARPA (Advanced Research Projects Agency) and has alternated between these names over the years. For simplicity, we will use the name "DARPA" throughout this report.

with fresh ideas, it has been granted flexible hiring authority that allows it to offer limited term appointments.

The primary recipients of DARPA money are researchers and research organizations in industry and universities, with smaller amounts going to US government and federally funded laboratories. Start-up firms have frequently played a lead role, especially if a technology has substantial commercial potential, as do microelectronics and computers, or when DARPA ideas could impact the long-term competitive position of existing firms' products. As suggested in Figure 1, DARPA acts as a catalyst for innovation by seeding research communities in promising new technology areas, making iterative investments in the underlying technology base from development through proof-of-concept. In some cases, DARPA funds large-scale demonstrations that integrate individual components. Performing a demonstration may require DARPA to act as a "system of systems" integrator, funding the engineering work required to meld different system functions into a new capability that is more than the sum of its parts.

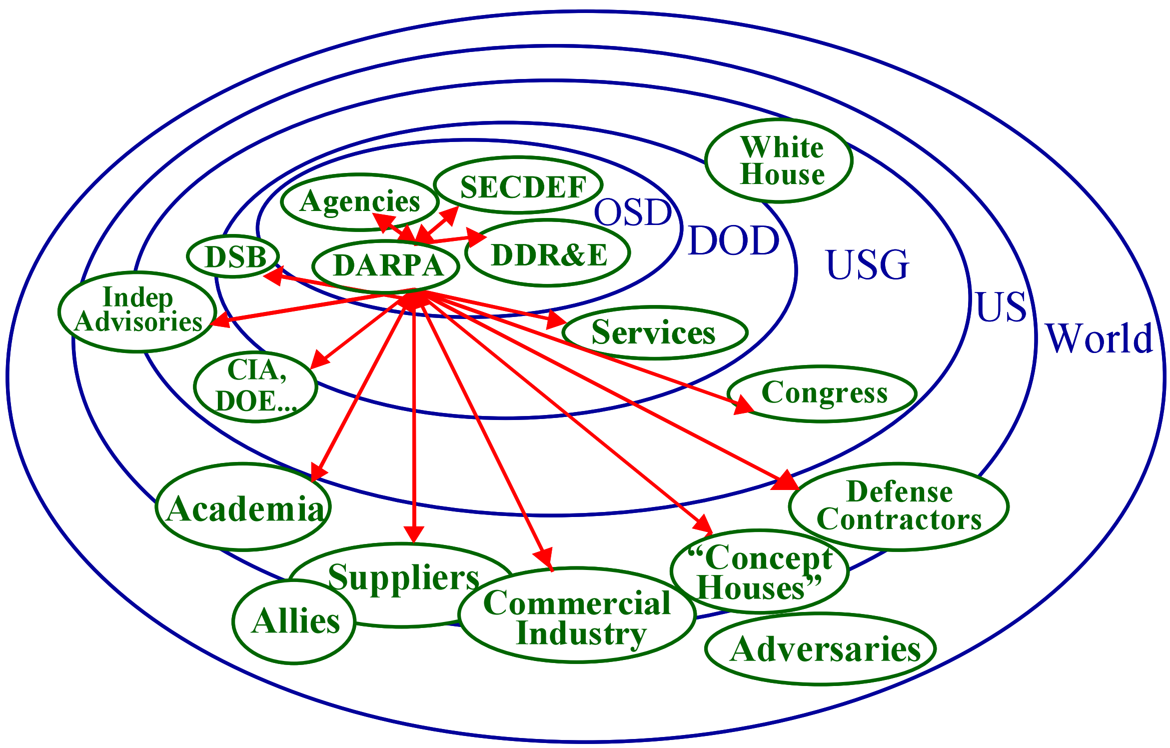

Figure 1. DARPA's Linkages with Outside Organizations

Because measuring progress toward a fundamental change is inherently problematic—revolutions do not follow a schedule—DARPA's managers and overseers face a difficult problem in assessing how well it is performing its mission. DARPA does not control the acquisition and deployment of new capabilities and, because its ideas may challenge existing programs and bureaucracy, it will be inherently difficult to find eager customers for them within the Services. This means that DARPA programs generally will not transition to Service acquisition and deployment in a straightforward way. DARPA's influence can also be hard to discern because the path from R&D to new defense capabilities is complex and nonlinear, involving numerous players inside and outside government who have different goals. Hence, there may be long delays between proof-of-concept and exploitation. DARPA funding often establishes research communities in new technology areas that subsequently draw on industry and Service funds once they are more mature and their relevance to military problems is clearer. By the time the resulting technology is embedded in systems, its origin in DARPA projects may not be evident. Contractors, having made substantial internal investments as part of their original partnership with DARPA, frequently promote new systems and concepts as their own and become identified with them.

Despite these measurement difficulties, recent studies have analyzed the rate and speed at which DARPA programs have transitioned into fielded defense systems.[2] Although DARPA has been quite successful by this metric, transition efficiency measures are most appropriate for well-defined R&D projects aimed at making incremental, near-term improvements in existing capabilities. DARPA's higher-risk, longer-term R&D agenda distinguishes it from other sources of defense R&D funding. Hence, this report works backwards by (1) identifying the major systems elements that underlie the substantial conventional warfighting superiority that US military forces currently enjoy; (2) identifying singular DARPA contributions to these military systems capabilities;[3] and

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2 J. J. Richardson, *Transitioning DARPA Technology* (Arlington, VA: Potomac Institute for Policy Studies, May 2001); and J. Goodwyn et al.; *Defense Advanced Research Projects Agency Technology Transition*, 1997, at www.darpa.mil. For a history of several other DARPA programs, see Richard H. Van Atta, Sidney Reed, and Seymour J. Deitchman, *DARPA Technical Accomplishments, An Historical Review of Selected DARPA Projects, Volumes I and II* (IDA Papers P-2192 and P-2429, respectively) (Alexandria, VA: Institute for Defense Analyses, February 1990 [Volume I] and April 1991 [Volume II]).

3 It does not assess DARPA's role in developing generic technologies—most notably modern microelectronics, computing, networking, and other information technologies—that underlie many of these military systems capabilities. See M. Mitchell Waldrop, *The Dream Machine* (New York, NY: Viking Penguin, 2001), for DARPA's role in these developments.

(3) assessing the process by which these capabilities moved from invention to military application. This report concludes by highlighting management practices that seem to facilitate the development and exploitation of fundamental military systems advantages, what is often referred to as an emerging "revolution in military affairs" (RMA).

B. What Is the Emerging RMA?

The leading-edge military capabilities of the US today are considered by many defense analysts to be at the forefront of an emerging RMA.[4] The term "RMA" signifies a fundamental shift in warfare: a coherent transformation encompassing military technologies, operations, organizations, training, culture, and strategy. An RMA is more than just the introduction of a new technology; it is a transformation in operations, organizations, and strategy that is often (but not always) enabled by technology. We use the term "disruptive capability" to denote technologies that are implemented in ways that foster profound changes in methods and strategy.[5]

RMAs are typically built around one or more disruptive capabilities. For example, the atomic bomb has enabled a disruptive capability, not just an improvement in strategic bombing. Combined with development of intercontinental ballistic missiles, it ushered in a transformation in military strategy, operations, and ultimately policy. Similarly, the disruptive capabilities demonstrated in Operation Desert Storm in 1991—stealth; standoff

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[4] The term "emerging RMA" is based on Andrew Marshall, Director, Office of Net Assessment (Office of the Secretary of Defense), *Memorandum for the Record*, "Some Thoughts on Military Revolutions—Second Version," August 23, 1993. The original articulation of the emerging RMA is credited to Soviet Marshall Nikolai Ogarkov in *Vsegda v Gotovnosti k Zashchite Otechestva* (*Always in Readiness to Defend the Homeland)*, Moscow: Voyenizdat, March 25, 1982, in which he described an emerging "reconnaissance strike complex."

[5] The definition of disruptive capabilities with respect to an RMA is derived from Richard O. Hundley, *Past Revolutions, Future Transformations: What Can the History of Revolutions in Military Affairs Tell Us About Transforming the US Military?* (Santa Monica: RAND Corporation National Defense Research Institute, 1999), p. 9. The concept of a disruptive technology/innovation itself can be traced back to Joseph Schumpeter's *Capitalism, Socialism and Democracy* (1942). Schumpeter describes capitalist economies as engines of "creative destruction" in which new firms adopt disruptive innovations that challenge existing firms' dominance. His concept was based on recognition that long-term profitability in a competitive environment depended on creating market inefficiencies that could then be exploited. Successful firms make above average profits over time by constantly innovating, i.e., by constantly disrupting the market. More recently, the term "disruptive technology" was popularized in Clayton Christensen, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* (Harvard Business School Press, 1997). He defines disruptive technologies as ones that "bring to the market a very different value proposition than had been available previously." Geoffrey Moore uses the term "discontinuous innovation" in *Crossing the Chasm* (Harper Business, 1991) to refer to "products that require us to change our current mode of behavior or to modify other products and services."

precision strike; and advanced intelligence, surveillance, and reconnaissance (ISR)—represented more than just improvements in US conventional warfare capabilities. Combined, they have allowed the US to "change the rules" of conventional warfare.[6]

While there is debate as to the definition, scale, and scope of the emerging RMA,[7] the pervasive impact of microelectronics and the various "information technologies" (IT) enabled by microelectronics is clearly a central driver. Faced with the "fog of war"—the difficulty of finding, characterizing, and controlling thousands of systems and forces distributed over a battlefield—the trend in military development prior to the IT revolution had been toward larger, faster, and more lethal systems that could prevail in one-on-one duels with competing forces. Military training and exercises emphasized rehearsing well-defined operations. Attackers could expect high losses when going after well-defended positions. But advancing microelectronics and IT are transforming these aspects of warfare in three related ways:

- Offering vastly superior solutions to informational problems associated with military control, with the hope of replacing the fog of war with "situation awareness"; distributed, real-time decision making; and adaptive self-organization
- Enabling weaponry to be smaller, lighter, and accurately deliverable from long distances
- Facilitating the development of entirely new weapons concepts that could overcome traditional defenses

IT-enabled forces have an "unfair advantage" in that they can mount many-on-one attacks by surprise from standoff distance, massing effects rather than massing forces. Improved ISR and communications permit adaptability rather than fixed procedures. Discriminating, real-time sensors mean that opponents increasingly have nowhere to hide. Hence, *the ability to exercise military control is shifting from forces with the best or the*

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6 William J. Perry, "Desert Storm and Deterrence," *Foreign Affairs*, Fall 1991, pp. 66–82.

7 There are four dominant schools of thought about the RMA: (1) *There is no emerging RMA:* Current changes in warfighting are evolutionary, not revolutionary; (2) *The emerging RMA is a technology-driven strategy* centered on sophisticated sensors and signal processing, embedded computers, and stealth, all of which now are nearing maturity; (3) *The emerging RMA is centered on achieving information dominance*—radical shifts in battlefield awareness, tactical decision making, and operational strategy—based on the integration into a "system-of-systems" of advanced sensors, C4I, semi-autonomous weapons, knowledge management tools, and realistic simulation.; and (4) *The emerging RMA is part of a broader socio-economic transformation that is engendering both new threats and new ways of adapting to them,* blurring distinctions between traditional concepts of "civilian" and "military," "operating forces" and "support," etc.

most individual weapons systems toward forces with better information and greater ability to quickly plan, coordinate, and accurately attack. This shift is the essence of the emerging RMA.

II. CONCEIVING DISRUPTIVE CAPABILITIES

A new notion of combat was demonstrated in Operation Desert Storm. While superior training, leadership, and individual equipment accounted for a large part of the allied victory, these factors alone cannot account for achieving a 1000:1 advantage in combat losses.[8] The combined impact of better battlefield information, the ability to suppress defenses, and the ability to strike precisely at high value targets demonstrated a new way of achieving and maintaining military control in which large platforms play a less important role. This section describes how strategic problems were defined and how DARPA reorganized itself to respond. Section III describes the refinement of these strategic concepts, their translation into specific "change state" experiments, and the efforts of OSD leadership to push Service implementation.

A. Strategic Challenges

The emerging RMA was shaped by strategic challenges facing the US in the wake of the Vietnam War, which exposed weaknesses in US military technology and morale. As the US began to disengage from Vietnam, national security leadership refocused attention on the Soviet Union. In particular, Warsaw Pact forces deployed in Europe opposite NATO had been significantly increased and qualitatively improved. The build-up of Soviet intercontinental nuclear forces had reached the point of rough strategic parity with the United States. Strategic nuclear parity diminished the credibility of NATO's planned use of theater nuclear weapons to counter the Warsaw Pact's advantages in conventional forces. Growing evidence of the effectiveness of Soviet integrated anti-aircraft systems, particularly in Vietnam and in the 1973 Yom Kippur War, called into question whether NATO could count on superiority in tactical aviation to offset the Warsaw Pact's advantage in ground forces. It was not deemed practical or politically feasible to increase military procurement and the size of the armed forces to match Warsaw Pact numbers.

In the early 1970s, US and NATO planners and policy makers supported sustained concept development efforts to better define the challenge and develop alternative

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8 Perry, "Desert Storm and Deterrence."

responses. Panels, boards, and conferences—some directly supported by DARPA—played an important role in the development, communication, review, and refinement of concepts. Although these gatherings were sponsored by government organizations, the work was independent. Organizational agendas and detailed mission requirements did not constrain consideration of controversial ideas, and intermediate government organizations were often bypassed.

Some of these deliberations focused on identifying core technologies that would support these new approaches. DARPA and the Defense Nuclear Agency (DNA) jointly funded the Long Range Research and Development Planning Program to "broaden the spectrum of strategic alternatives" available to the President and the Secretary of Defense against "limited Soviet aggression."[9] As part of the program, various panels and contractors considered integrated nuclear and conventional concepts, technologies, systems, and doctrine to meet a variety of military contingencies. The Strategic Alternatives Panel articulated potential conflict scenarios in Europe and Asia using real maps, detailed information about actual targets, and realistic time sequences, while also taking into account political considerations. The Advanced Technology Panel and Munitions Panel described specific weapons capabilities that would be needed to address these threat scenarios in new and strategically superior ways. A subsequent effort sponsored by DNA developed and verified detailed predictions of how the Warsaw Pact would actually assault NATO and suggested ways of disrupting these attacks by using only a few nuclear weapons per Army division, or—importantly—by using sufficiently accurate conventional weapons.[10]

The key idea that came out of these efforts was that there were alternatives to a primarily nuclear response to the Soviet threat. In particular, these deliberations began to converge around various new defense concepts that emphasized *standoff precision strike*. The problem of standoff precision strike was further defined in terms of the "integration of a wide range of technologies: target detection, recognition and location; delivery vehicles and munitions; and weapon navigation and guidance. This dictate(d) a unified approach to development in these areas and the establishment of operational procedures for effective

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9 Final Report of the Advanced Technology Panel, *ARPA/DNA Long Range Research and Development Planning Program*, April 30, 1975, pp. 1–2; and Minutes of the First Meeting of the Advanced Technology Panel, August 31, 1973.

10 DNA was well positioned to support this work, as it had been dealing with operational issues for years in support of commands and had both military and analytical staff. In contrast, conventional development communities (including DARPA) did not have similar operational planning or threat assessment staffs.

integration and employment of both targeting and weapons systems."[11] Well-connected defense analysts such as Albert Wohlstetter, Joseph Braddock, Andrew Marshall, Donald Hicks, and Fred Wikner promoted these concepts throughout the defense community and to top OSD and Service leadership.

B. DARPA Responses

During this period of strategic foment, DARPA was being reorganized and refocused to increase its effectiveness in addressing military needs. DARPA had been established in 1958 with three presidentially directed initiatives: space, missile defense, and nuclear test detection. DARPA also initiated research efforts in areas such as computer science, behavioral science, and materials, as part of its broader charter to prevent the US from suffering technical surprise. By 1966, when Dr. John S. Foster, Jr., became Director of Defense Research and Engineering (DDR&E), the space programs had been transferred to the National Aeronautics and Space Administration (NASA) and the Services, but DARPA was still managing most of the original missile defense and nuclear detection programs. Although DARPA was well regarded for its management of scientific work, Foster and his staff wanted the agency to be more aggressive in transferring technologies to the Services. They were concerned that DARPA was becoming regarded as "DoD's NSF" (National Science Foundation), an organization focused on long-term development of scientific principles and talent, as opposed to one that produced results.

Although DARPA still formally reported directly to the Secretary of Defense, Foster took control of the organization and brought in Eberhart Rechtin as DARPA Director. Rechtin accelerated the transfer to the Services of technologies developed under the missile defense program DEFENDER.[12] Additionally, several basic science programs and their budgets were moved to NSF. Taken together, DARPA's budget was cut almost in half within 2 years. Rechtin pushed DARPA program managers (PMs) to develop stronger relationships with potential Service users.

Rechtin's successor as DARPA Director, Steven Lukasik, continued the agency's transformation into a tighter, more structured organization. With the transfer of its more

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[11] Final Report of the Advanced Technology Panel, *ARPA/DNA Long Range R&D Planning*, p. 6.

[12] When the Services agreed to take on the work and pay for it, it was understood that they would mold it to their own purposes. However, this did not mean that DARPA ceased to contribute new ideas and technical approaches.

mature development projects such as DEFENDER, the bulk of DARPA's remaining programs were exploratory. To develop new thrust areas and themes, Lukasik funded several studies—including the Long Range Research and Development Planning Program whose steering committee he chaired—aimed at better understanding defense needs that new technologies could address. He also worked to build stronger relationships between DARPA and the operating commands, the Joint Chiefs of Staff, and US allies. He actively supported DARPA PMs in seeking out forward-thinking officers to become "customers" for DARPA projects.[13]

In 1974, after serving as DDR&E for 8 years, Foster departed for industry and was succeeded by Malcolm Currie. Currie, Director of Hughes' corporate research laboratory, was the first person to fill this role whose background was primarily in electronics. His predecessors all came from the nuclear weapons world. Currie appointed George Heilmeier from the DDR&E staff—Heilmeier also had a corporate electronics background—as the DARPA Director and gave him a mandate to refocus and scale up DARPA's programs. Currie and Heilmeier believed that it was important for DARPA to take on large programs on a selective basis, refocusing DARPA on "basic research and big projects that could make a difference."[14] A particular concern for Currie, based on guidance from Secretary of Defense Schlesinger, was the need to harness emerging technology capabilities to address the challenge of Soviet military buildup.

Toward these ends, Heilmeier consolidated most of DARPA's programs into major, outcome-oriented thrust areas. In some cases, there would be an emphasis on actual demonstrations, making the programs much bigger and riskier than programs pursued during the previous decade but similar in some ways to the type of programs that DARPA had pursued in its early years. Heilmeier conceived a new program category for

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13 Stephen Lukasik, interview, July 24, 2001. Nicolas Lemann put it well in "Dreaming about War" (*The New Yorker*, July 16, 2001, p. 37): "Big changes many times happen...where only a small part of the force is really changed…because, within the officer corps, there is a subgroup that thinks that the available technology can be used in some novel way, and it's either supported enough by the top people or somehow or another gets allowed to be tried. And then comes the war, and real combat that shows that, by God, these guys were right—that this is the thing that really works."

14 Heilmeier promulgated a set of guideline questions—the "Heilmeier catechism"—which are still applied today for DARPA program management: What are you trying to accomplish? How is it done now, and with what limitations? What is truly new in your approach which will remove current limitations and improve performance? By how much? If successful, what difference will it make? What are the mid-term, final exams, or full-scale applications required to prove your hypothesis? When will they be done? What is the DARPA exit strategy? How much will it cost? (excerpted from DARPA presentation). See also "1993 Tech Leader Dr. George H. Heilmeier: President and CEO, Bellcore, Livingston, N.J.,"), *Industry Week*, December 20, 1993.

these thrusts, called Experimental Evaluation of Major Innovation Technologies (EEMIT), to protect the rest of DARPA funding should these large development programs run into difficulties or be cut by Congress. Currie and Heilmeier also promoted greater "customer pull" by pushing DARPA PMs to secure some form of Service commitment and, in some cases, actual funding contributions for their programs. Importantly, Currie made it a priority to develop relationships with Service leadership.

In 1977, William Perry succeeded Currie in the DDR&E role, which was upgraded and renamed Under Secretary of Defense for Research and Engineering that year.[15] Secretary of Defense Harold Brown made it clear that he wanted Perry to help him "deal with the Soviets."[16] Heilmeier, who stayed on as DARPA Director, briefed Under Secretary Perry in detail on the technology thrusts he and Currie had begun at DARPA in 1975. Perry—whose background was also in defense electronics, particularly surveillance systems—perceived that the combat effectiveness of NATO forces could be substantially multiplied by exploiting some of these technologies. However, given their revolutionary nature, implementation would require significant, focused management effort.

Under Secretary Perry began by elevating what had been a technology strategy under Currie to the level of a broad defense strategy, which he and Secretary Brown labeled the "Offset Strategy."[17] Its central idea was that synergistic application of improved technologies—electronic countermeasures, command and control, stealth, embedded computers, and precision guidance—would allow the US to overcome Soviet defenses and destroy Soviet tanks. Then, with the Offset Strategy as a guide and the Secretary of Defense's imprimatur, Perry focused the attention and support of high-level DoD decision makers, Service chiefs and Congress to speed several important technologies from concept to implementation. Between 1977 and 1981, DARPA's budget almost doubled. This mobilization of effort and funding around new warfighting concepts, as opposed to just useful technological capabilities, could be considered the beginning of the emerging RMA.

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15 In 1986, the position of DDR&E was reestablished at a lower level, reporting to the Under Secretary of Defense for Acquisition, the replacement position for the USD(R&E). See Cheryl Y. Marcum, Lauren R. Sager Weinstein, Susan D. Hosek, and Harry J., Thie, *Department of Defense Political Appointments: Positions and Process*, Report MR-1253-OSD (Santa Monica, CA: Rand Corporation, 2001), pp. 53–67.

16 Interview with William J. Perry, June 6, 2001.

17 Charles Lane, "Perry's Parry: Reading the Defense Secretary's Mind," *The New Republic*, June 27, 1994.

III. IMPLEMENTING DISRUPTIVE CAPABILITIES

The central technologies of the Offset Strategy—stealth; standoff precision strike; and advanced intelligence, surveillance, and reconnaissance (ISR)—are highlighted here. DARPA played formative roles in these areas, not only in achieving technical results but also in moving them from technology concepts to military capabilities.

A. Stealth Combat Aircraft

The F-117A "Stealth Fighter" helped the US achieve early air superiority in Operation Desert Storm by striking critical, heavily defended targets. It did so in the face of the same type of Soviet anti-aircraft systems that had been effective in Vietnam and the Yom Kippur War. In championing stealth, DARPA harnessed industry and Service lab ideas to pursue a radical new warfighting capability. Stealth combat systems had not been pursued because the Services lacked a strong interest in such a nontraditional 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 aircraft demonstration system, something DARPA had never done before. 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. 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.

In 1974, Chuck Myers (director of Air Warfare Programs in the Office of the 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 tactical combat aircraft with greatly reduced radar, infrared, acoustic, and visual signatures. A primary objective was to use only passive measures (coatings and shaping) rather than depending on support aircraft carrying jammers.[18] Such a plane would allow for new types of deep

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[18] Interview with Robert Moore, July 30, 2001. See also Van Atta et al., *DARPA Technical Accomplishments, Volume II* (Alexandria, VA: Institute for Defense Analyses, April 1991), p. 10-4.

air attacks, 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 had been employed in classified reconnaissance aircraft (both manned and unmanned). However, there were no serious efforts to employ such capabilities on a weapons platform. To do this, significant advances in radar cross-section reduction were needed to overcome Soviet integrated anti-aircraft systems. Myers wanted to fund aircraft companies to propose conceptual designs. Coincidentally, shortly after the Myers-Moore meeting, DDR&E Currie sent out a memo stating that he was not satisfied with innovation he saw coming out of DoD research. The memo also invited organizations to propose radical new ideas. Representing the TTO Office, Moore nominated the "Harvey" idea, renaming it "High Stealth Aircraft."[19]

Around the same time, Ken Perko was transferred into 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.[20] 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 under way, Lockheed's Russ Daniels was informed of the project during a visit with Myers. Lockheed had not been invited to participate initially because it was not considered to be active in tactical aircraft. Ed Martin, director of Lockheed science and engineering, contacted DARPA and requested permission to participate in the first phase concept development, without compensation. DARPA director Heilmeier granted his request.[21]

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19 The term "stealth" was borrowed from anti-submarine warfare, in which the problem was to prevent submarine detection.

20 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, 1997), p. 13.

21 Ibid., p. 14-15. Lockheed aggressively sought to be included, lobbying several high-level OSD and Air Force officials, arguing that they should be brought into the project. (Interviews with Robert Moore, July 30, 2001, and George Heilmeier July 13, 2001. See also Ben Rich and Leo Janos, *Skunk Works* (Boston, Little, Brown and Company, 1994), p. 63.

By the summer of 1975, it was clear that only Lockheed and Northrop had credible, near-term concepts for making aircraft radically less visible to enemy anti-aircraft radar. Perko, Robert Moore, and George Heilmeier met to develop a strategy. Considering the potential impact of the anticipated advances, they decided that a full-scale flight demonstration would be needed to make the results convincing. Heilmeier insisted that the program should 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 performance compromises 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 Air Force R&D priorities, most notably the Advanced Combat Fighter program (which eventually became the F-16).[22]

Thanks to Currie's earlier efforts to establish relationships with 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.[23]

Lockheed won the sole Phase 2 award, in part due to the record of its "Skunk Works" for on-schedule accomplishment of high-risk, high-classification projects. However, DARPA also wanted to preserve the expertise that Northrop had developed. It therefore encouraged Northrop to maintain its team, which shortly thereafter engaged in DARPA-sponsored design studies for the Battlefield Surveillance Aircraft program.[24] These studies led to the TACIT BLUE program that, in turn, provided the technology for the B-2 stealth bomber program and for advanced cruise missiles.

The Phase 2 program—HAVE BLUE—began in 1976. HAVE BLUE was a quarter-scale proof-of-concept aircraft designed to evaluate Lockheed's concept for "very

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22 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.)

23 Interview with Malcolm Currie, June 11, 2001.

24 Aronstein and Piccirillo, *Have Blue and the F-117A,* p. 33.

low-observable" capabilities while meeting a set of realistic operational requirements. The development program at Lockheed's Skunk Works was managed 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 in the face of many fundamental uncertainties.[25]

Successful flights of HAVE BLUE planes in 1977 made it clear that a stealthy aircraft could be built. 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 accelerated development of a real weapons system. Secretary of Defense Brown agreed to make the development of stealth aircraft "technology limited" as opposed to "funding limited." The DARPA stealth program was then 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 and General Alton Slay. The objective was to build and deploy a wing of stealth tactical fighter-bombers (75 planes) as rapidly as possible. Furthermore, in order to obtain the largest possible technical lead, it was deemed necessary to hide the acquisition by making SENIOR TREND a highly secret "black" program.[26]

Perry established efficient and effective stealth program management procedures. Changes in mission and redirection of funding are common problems that derail programs in the traditional acquisition cycle, in which a program must regularly defend its budget against other programs and respond to the preferences of members of Congress. Perry's hands-on management efforts helped avoid these problems. 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 caused by bureaucratic delays, 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

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25 Ibid., pp. 60 and 137.

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

(UAVs), and strategic bombers, as well as stealth countermeasures.[27] Congressional support was secured and, once gained, proved indispensable. Because the program was highly classified, special access subcommittees of the House and Senate Armed Services Committees were established.

The Air Force 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. The first F-117A was delivered in 1981, and 59 were deployed by 1990.[28] In 1991, the F-117A was an outstanding success in Operation Desert Storm, in the face of the same type of Soviet anti-aircraft systems that had been effective against US tactical aircraft in Vietnam and the Yom Kippur War. It continues to serve with distinction today.

US adversaries are still working to contend with the F-117A. A recent report on Chinese military modernization noted efforts to build ultrawideband and multistatic radars and to fuse data from networks of emitters and sensors in order to reduce the value of stealth aircraft.[29] Only one F-117A has been lost to anti-aircraft fire in combat. This occurred on March 27, 2001, during Operation Allied Force in Kosovo. (After a second F-117A was damaged in Kosovo, Navy EA-6B Prowlers accompanied all F-117A and B-2 aircraft flying there.[30]) In just over a decade since its first use in combat, stealth has become an accepted capability that is now integrated into a number of Air Force weapons systems—the F-22 and Joint Strike Fighters, various cruise missiles, and unmanned aerial vehicles (UAVs). Stealth has been pursued but not widely implemented for ground and sea-based systems.

B. Standoff Precision Strike: Air Force and Army

Perhaps the most vivid images of Operation Desert Storm were the video clips of precision guided munitions striking their targets. This capability is based on myriad technologies for finding, hitting, and destroying targets on the battlefield under a variety of

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27 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 Navy.

28 Aronstein and Piccirillo, *Have Blue and the F-117A,* p. 127.

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

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

conditions. DARPA worked for years on these problems, as well as on the related problems of deciding which targets to attack and assessing post-attack damage. More importantly, DARPA took the initiative in demonstrating how these various technologies could be integrated into a "system of systems" to produce an ambitious joint operational concept that would revolutionize the battlefield. Many of the technologies promoted in this effort have been fielded, but only in modified forms that constitute a less joint perspective.

As in the case of stealth, current standoff precision strike concepts originated in efforts in the early 1970s (some of which DARPA funded) to assess the national security environment and define alternatives that would allow the US "to respond flexibly to a military threat from an aggressor nation."[31] The primary goal was defeating large numbers of dispersed Soviet armored vehicles without being forced to resort to nuclear weapons. In 1976, DDR&E Malcolm Currie described the Soviet capabilities facing NATO:[32]

- 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 (with greater range and firepower than our own), rapid-fire rocket launchers, and mine-laying systems—all mass produced and providing, in total, a formidable suppression capability.
- Ground attack aircraft with a 400% increase in payload and 250% increase in range.

Part of the US response was a major modernization program built around the "Army Big Five:" the M-1 Abrams Tank, the M-2 Bradley, the Multiple Launch Rocket Systems, the Blackhawk Helicopter, and the Apache Helicopter. Concurrently, the Army created the Training and Doctrine Command (TRADOC) to develop doctrine for exploiting this modernization to fight and win a conventional war against the Warsaw Pact in Central Europe. The second commander of TRADOC, General Donn Starry, rewrote

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31 Final Report of the Advanced Technology Panel, *ARPA/DNA Long Range R&D Planning*, p. iv.

32 Testimony of Malcolm Currie to the US Congress, Senate Committee on Appropriations, Department of Defense Appropriations for FY77, Part 4: Procurment/RDT&E, February 3 and 17, March 16, 18, 23, & 31, 1978, 76S181-68, pp. 888–889.

Army doctrine around the Big Five and emerging technologies of the 1970s and 1980s. In Starry's own words:

> In May 1977 I returned to Israel's battlefields to revisit action at the operational level and then translate that experience to Europe's environment. This led to a concept for extending the battlefield in time (the campaign) and distance (the theater of operations). Most importantly, it resulted in requirements for long-range surveillance and target acquisition systems and long-range weapons systems with which to find and attack Soviet style follow-on echelons.[33]

Around the same time, the results of a DNA-sponsored follow-on effort to the Long-Range Research and Development Planning Program was being briefed around DoD. The study group, headed by Joseph Braddock, developed detailed predictions of how the Warsaw Pact would execute attacks. Their results suggested ways of disrupting these attacks with only a few nuclear weapons per Army division, or—importantly—with highly accurate conventional weapons. Five technical developments were proposed as the conceptual solution to the problem of disrupting a Warsaw Pact offensive by conventional means:[34]

- An airborne radar to detect enemy movement up to 300 kilometers into enemy territory
- A ground surveillance radar to detect targets for the close battle out to 20 kilometers
- A guided missile "bus" that would deliver multiple precision munitions to the target area, kept on course by inertial sensors and friendly radar tracking
- Terminally guided submunitions that, after release from the bus, would seek targets and automatically attack them
- A rapid, all-source targeting system, combining and analyzing inputs from the radars, intelligence sources, and message traffic

Robert Moore, Director of DARPA's Tactical Technology Office (TTO), was regularly briefed on threat assessments and response concepts such as these. In 1975, Leland Strom, a radar expert and PM on the DARPA/TTO staff, came to Moore with the concept of using a moving target indicator (MTI) radar to guide a missile to ground

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[33] Donn A. Starry, "Reflections," in George F. Hofmann and Donn A. Starry (eds.), *Camp Colt to Desert Storm. The History of US Armored Forces* (Lexington, KY: University Press of Kentucky, 1999), pp. 551–552.

[34] Fred Wikner, formerly of DNA and former Scientific Advisor to Gen. Abrams in Vietnam, developed one of the first integrated concepts for combining these elements.

targets, and then use terminally guided submunitions to destroy the targets. Around the same time, Moore received an industry briefing from Mr. Robert Whalen of Martin Marietta outlining a battlefield interdiction missile system that would employ the Patriot missile (T-16) carrying terminally guided submunitions with electro-optical seekers. (Robert Parker of Vought, whose missile would end up being selected for Army development, was also a contributor.) Based partly on these ideas, Moore proposed the Integrated Target Acquisition and Strike System (ITASS) as a DARPA program to develop and demonstrate actual capabilities. Moore asked Lincoln Laboratory to develop and assess the concept, including the actual systems to be used and the feasibility of enabling technologies.[35]

To some, the ITASS program seemed inappropriate for DARPA. The primary thrust would not be developing advanced technology but rather integrating existing and relatively near-term technology, much of which had never been deployed. It was also a major systems integration effort that would entail a very large investment. The concept gained momentum, however, when a 1976 Defense Science Board (DSB) Summer Study reviewed the array of available technologies—radars, missiles, submunitions, sensors, information fusion systems—and concluded that they could be integrated into a feasible system. The DSB report gave strong backing to the ITASS concept. The DSB noted that no attempt had been made to demonstrate the approach and recommended that this be done. Reinforcing the idea in testimony before Congress, Under Secretary William Perry stated his belief that such a standoff precision strike capability would represent "our greatest single potential for force multiplication."[36] He went on to testify as follows:

> 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….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.[37]

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35 Interview with Robert Moore, July 30, 2001.

36 Testimony of William Perry to the US Congress, Senate Committee on Armed Services, Department of Defense Appropriations for FY77, Part 8: Research and Development, February 28, March 7, 9, 14, 16, 21, 1978, 76S181-68, p. 5598.

37 Ibid.

The ASSAULT BREAKER program, embodying most of the ITASS concept, was approved by incoming DARPA Director Robert Fossum in 1978. Fossum was concerned that the level of systems coordination might make the concept operationally "fragile" in a real battle environment. But he felt it had sufficient potential to address the Soviet threat to merit going forward, and he had confidence in the people behind it.[38] ASSAULT BREAKER brought together developments in long-range tactical missiles, standoff airborne synthetic aperture and moving target indicator radars, precision-guided submunitions, and ground-based sensor fusion. The concept (Figure 2) involved an airborne synthetic aperture radar (SAR) with MTI capability (PAVE MOVER) sending data to a processing and fusion center in order to locate and track targets. A long-range ground-to-ground missile with a "bus" carrying multiple precision-guided submunitions would be launched to the target area, with midcourse adjustments provided by PAVE MOVER. Once released above the target area, these submunitions would use terminal guidance systems to strike the target array.

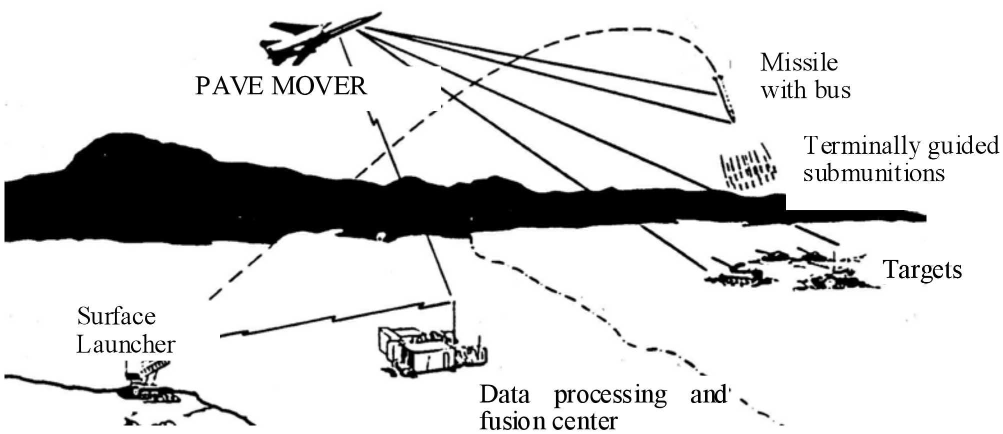

Figure 2. ASSAULT BREAKER Concept of Operation

The ASSAULT BREAKER program had four phases. In the first phase, various component technologies were improved to necessary performance levels. This involved focused efforts in basic, crosscutting technologies that DARPA had been investing in for years; these included infrared detectors, focal plane arrays, millimeter wave radar, laser radar, and automatic target recognition algorithms. For example, PAVE MOVER (built

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38 Interview with Robert Fossum, February 7, 2002.

by Northrop and Grumman under DARPA PM Nicholas Willis) was an adaptation of the joint DARPA-Air Force Tactical Air Weapons Direction System (TAWDS).[39] In phase two, different contractor approaches to system components were tested in parallel, and small-scale development efforts were undertaken to work out problems. In the third phase, gradually more complex systems integrations were attempted. Finally, in the fourth phase, most of the pieces were tested together in one of the more complex and integrated DARPA demonstrations ever attempted. In December 1982, at the White Sands Missile Test Range, a missile guided by a PAVE MOVER radar dispensed five submunitions above a field with five target tanks. Using terminal guidance, the submunitions homed in on the targets and made five direct hits.

Technically, the demonstration was a success. There was also evidence that the Soviets were aware of emerging US standoff precision strike capabilities and, in response, experimented in their training with ways to overcome it.[40] But implementation as a fielded standoff precision strike capability proved to be circuitous and incomplete. The primary reasons: (1) ASSAULT BREAKER called for unprecedented cooperation between the Army and the Air Force; and (2) the concept overlapped with other Service acquisition priorities.

On many levels the necessary operational cooperation was forthcoming. In 1976, TRADOC published a field manual that stated, "The Army cannot win the land battle without the Air Force."[41] The concept was refined through years of work between TRADOC and the Air Force's Tactical Air Command in a joint office known as the Directorate of Air-Land Forces Application.[42] To help coordinate and transition the ASSAULT BREAKER program, Under Secretary Perry established an Executive Committee composed of the three Service R&D Secretaries, with input from general officers from the Services' Systems Command, Development Command, TRADOC, and Tactical Air Command.[43]

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39 Testimony by Malcolm Currie, US Congress, Senate Committee on Appropriations, Department of Defense Appropriations for FY77, Hearing, Feb 3, 17, March 16, 18, 23, 31, 1976, pp. 5-5 & 5-6.

40 William E. Odom, *The Collapse of the Soviet Military* (New Haven, CT: Yale Univesity Press, 1998), p. 76.

41 FM 100-5, as cited in Rebecca Grant, "Deep Strife," *Air Force Magazine*, June 2001, p. 54. Italics in original.

42 Harold R. Winton, "Partnership and Tension: The Army and Air Force Between Vietnam and Desert Shield," *Parameters*, Spring 1996, p. 104.

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

Still, each Service continued to maintain its own acquisition and deployment priorities. Each had high profile programs such as the M1 tank and F-16 fighter that it wanted to protect, and each already had separate munitions development efforts for destroying hardened and mobile ground targets. The Air Force was exploring ways to deliver munitions from the air with the F-16, using laser-guided bombs and cruise missiles. They also had an ongoing wide area anti-armor munitions (WAAM) project, which included the WASP, a small, high velocity air launched missile, and the SKEET, a self-forging fragmentation munition. Meanwhile, the Army was looking at ground and helicopter delivered systems such as the nonnuclear Lance missile and the General Support Rocket System (which ultimately became the Multiple Launch Rocket System or MLRS). The Army was also developing terminally guided submunitions (TGSM) for its tube artillery and rocket systems.

In 1983, in response to congressional pressure to consolidate duplicative, nonintegrated Service programs for rear echelon attack into a more rational development approach that shared technology and resources, James Wade (Principal Deputy Under Secretary for Defense Research and Engineering) created a set of "J" or Joint programs in OSD. These programs included Joint Surveillance Target Attack Radar System (JSTARS), based on the PAVE MOVER radar, and the Joint Tactical Missile System (JTACMS), based on the ASSAULT BREAKER missile, as well as joint data fusion, radar homing, and cruise missile programs. In May 1984, the Chiefs of Staff of the Army and Air Force signed a Memorandum of Agreement known as the "31 Initiatives," covering doctrinal issues and joint management for certain of these programs. An Office of Conventional Initiatives under James Tegnelia, former ASSAULT BREAKER PM at DARPA, was established within the Office of the DDR&E to oversee Service follow-through with the integrated programs.

Several of these programs led to successful system acquisitions. The PAVE MOVER radar became JSTARS, perhaps the best example of a truly joint capability. JSTARS is operated by the Air Force but includes Army systems designed to provide dedicated support to ground commanders. JSTARS provides a common battle management and targeting capability for situation assessment and coordination of attacks from beyond the range of antiaircraft weapons. It combines radar, airborne battle management workstations, airframe, data link, and ground stations to locate, track, and classify tracked and wheeled vehicles beyond ground line-of-sight during the day and night and under most weather conditions. JSTARS flight test aircraft were successfully employed in Desert Storm. They flew 49 combat sorties and saw more than 500 combat hours, garnering praise for their ability to track mobile Iraqi forces.[44]

With other systems, however, different operational approaches and system priorities led to divergent acquisition efforts. The JTACMS program originally aimed to develop a common Air Force-Army standoff attack missile. It was soon restructured to allow separate but complementary systems and later abandoned by the Air Force altogether in favor of cruise missile development. The Army received approval to develop its own Army Tactical Missile System (ATACMS): a ground-launched missile system consisting of a surface-to-surface guided missile with an anti-personnel/anti-materiel (APAM) warhead with the ability to engage targets at ranges well beyond the capability of existing cannons and rockets. During the Gulf War, 32 ATACMS missiles were fired against targets that included surface-to-air missile (SAM) sites, logistics sites, artillery and rocket battery positions, and tactical bridges.

One aspect of the ASSAULT BREAKER—terminally guided submunitions—has been particularly slow to develop. The history of standoff precision strike after ASSAULT BREAKER points to some of the issues.

In the early 1980s, leadership in OSD and DARPA realized that, in addition to massed Soviet armor, mobile, elusive, hiding targets also presented a strategic challenge. Intelligence data and analyses revealed that the Warsaw Pact was fielding numerous short- and long-range mobile missiles. Training exercises and operations had been studied to determine their concept of operations, hiding strategies, and "shoot and scoot" tactics, as well as their techniques for camouflage, concealment, and deception. The deficiency in US capabilities to attack such targets became clear in Desert Storm in 1991. "The Great Scud Hunt" showed that Iraqi Scud missiles could not be found and destroyed with manned aircraft in spite of a massive sortie rate.

To understand the technical and operational problem, one must clearly distinguish precision from smartness. Precision weapons are ones that can hit their targets with high accuracy. The capability goes back 60 years to the German wire guided bomb of WWII. The laser-guided bomb of Desert Storm first saw service in Vietnam 20 years earlier. Even today's Global Positioning System (GPS)-guided JDAM is precise but "dumb" in

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44 While providing surveillance during the battle for Khafji, JSTARS detected a follow-on force of 80 Iraqi vehicles heading toward the town. This force was engaged and stopped by tactical aircraft. When the Iraqi army was retreating from Kuwait City, JSTARS provided real-time information that allowed tactical aircraft to interdict and destroy the Iraqi mechanized columns. <http://www.fas.org/irp/program/collect/jstars.htm>

that it does not pick its targets. Smart weapons are ones that can both find and hit targets with high accuracy.

The Desert Storm experience helped congeal various efforts to develop terminally guided precision munitions as part of systems that could address the problem of mobile, elusive targets hiding in difficult terrain. The concept was to put sensors and weapons in the target area at the same time so that targets could be attacked as they appeared. This was believed to be the only way to attack time-critical, fleeting targets. DARPA had been working aspects of the problem for several years. The 1985 Smart Weapons Program sought to develop a modular family of weapons that included various intelligent munitions and an Autonomous Air Vehicle, a smart bus that could autonomously search large areas and precisely deliver smart or dumb munitions to target arrays. The Smart Weapons Program blended lessons from ASSAULT BREAKER with loitering, unmanned aircraft concepts and the 1983 DARPA Automatic Terminal Homing (ATH) Program. (ATH had demonstrated day/night imaging sensors and processing algorithms that could perform both terrain matching with wide fields of view and target recognition in the last kilometer of flight.) Figure 3 illustrates the Smart Weapons Program concept as applied to attacking mobile missiles.

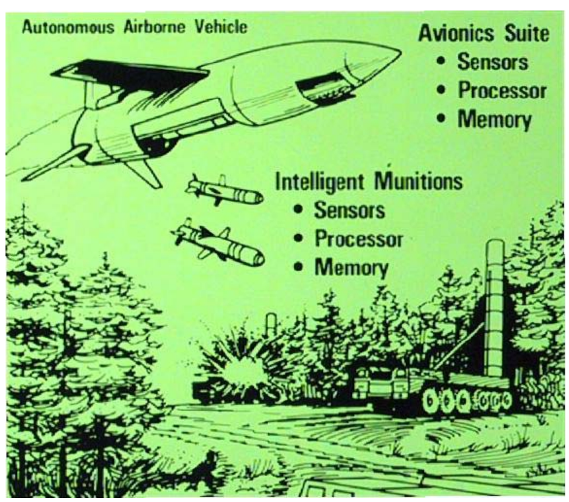

Figure 3. DARPA Smart Weapons Program Concept

Thirsty Saber, the second phase of the Smart Weapons Program, sought to define a transition path for the concept. The program focused major effort on killing targets hidden by camouflage or partial canopy with up to 50% obscuration. In response to the problem of finding and destroying Iraqi Scud missiles, an accelerated program, Thirsty

Warrior, was aimed at fully integrating the Thirsty Saber capabilities into a cruise missile. There was high-level support for Thirsty Warrior despite its high cost, but the impetus waned rapidly following the Gulf War. Subsequently, the DARPA WARBREAKER program reexamined the mobile target problem. To sort through the options, a Tiger Team led by a DARPA PM and an external chairman was formed, overseen by an Advisory Group reporting to the Director of DARPA. Rather than incorporate smart weapons, WARBREAKER came to focus on just an architecture for finding mobile, elusive targets rather than on a complete reconnaissance/strike capability, as ASSAULT BREAKER had done.[45] It was hoped that if the problem of finding mobile, elusive targets could be solved, the Air Force and Navy would be able to kill the targets. However, a combined hunter-killer system using loitering, unmanned weapons is a disruptive capability that has yet to be fielded.

There are several reasons why smart weapons have been resisted:

- Smart weapons change operational concepts and doctrine.

The idea that one might fire a weapon without directly viewing and positively identifying the target is not permitted under current rules of engagement. It represents a new way of thinking. Military concepts of operations have been designed for years around unguided and command guided weapons. In Desert Storm, more than 90% of the bombs used were unguided, and to the extent that precision strike weapons were used, they were laser-guided bombs or pre-programmed systems such as the Tomahawk Cruise Missile. Command guided weapons were also the dominant precision weapon used in Afghanistan, generally by special operations forces that sent GPS coordinates to bombers dropping JDAMs. This solution worked, but these soldiers were put at considerable exposure and risk. Had the environment on the ground not been as favorable, they would not have survived long in their role as target designators. Also, command designated weapons have limited effectiveness against moving, hiding targets. (However, Predator UAVs armed with a laser designator and Hellfire missiles were used in battle for the first time in Afghanistan.)

- Smart weapons are still evolving.

Technology options for smart weapons are constantly changing, making it hard to choose a solution and stick with it. Steady advances in computers, software, and sensors

[45] The success of JSTARS in Desert Storm made it a prominent candidate for tracking all moving objects on the ground. WARBREAKER added the capability of maintaining a real-time database of all vehicles and mobile weapons on the battlefield.

also lead to rising expectations and concomitant complaints that current smart weapons are not "smart enough." This points to a related problem of evaluation. As a new capability, it could take years to provide users with evaluation tools that can test them over their full functional range with statistically meaningful results.

- Smart weapons are too expensive.

Although smart weapons are indeed costly, their cost per target killed should be lower than that for any other method of attack on mobile, elusive targets, considering the substantial costs of trying to attack such targets from conventional platforms. Desert Storm proved just how troublesome and expensive it could be to try to attack these targets using manned aircraft with command-guided weapons. In addition, a December 1996 review suggested that smart weapons might actually reduce the effectiveness of enemy deception and decoys while lowering the danger of fratricide. Fratricide accounted for more than a third of casualties in Vietnam and the majority of US casualties in Desert Storm and in Afghanistan.

- Smart weapons reduce force structure.

This is perhaps the hidden issue in the complaint about smart weapons cost. There are natural tradeoffs between how "smart" a munition needs to be relative to the system that delivers it to the target area. Smart weapons could in effect reduce the need for manned platforms by providing higher kill ratios per ton of ordnance delivered in battle. In budget competitions, Services tend to protect their large manned platforms for fear of not having enough delivery systems.

In the final analysis, a truly standoff precision strike capability against hardened and mobile targets remains elusive. DoD Science and Technology plans continue to call for "advances in sensors, C2 interoperability, battle management…lethality, (and) precision-guided munition enhancements" to support standoff precision strike. Figure 4 from a 1997 DoD report still looks remarkably like the ones shown to Congress in the late 1970s illustrating the original ASSAULT BREAKER concept.[46] It includes several ASSAULT BREAKER components: JSTARS (from PAVE MOVER), Army Tactical Missile System, and precision munitions.[47] It remains to be seen whether recent US experiences will result in the type of top-level focus and effort required to implement this truly disruptive capability.

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[46] Vice Chief of Staff of the Army, General Ronald Griffith, reviewing a DDR&E briefing package on automatic target recognition in preparation for the Joint Requirements Oversight Council (JROC).

[47] US Department of Defense, *Joint Warfighter S&T Plan*, 1997.

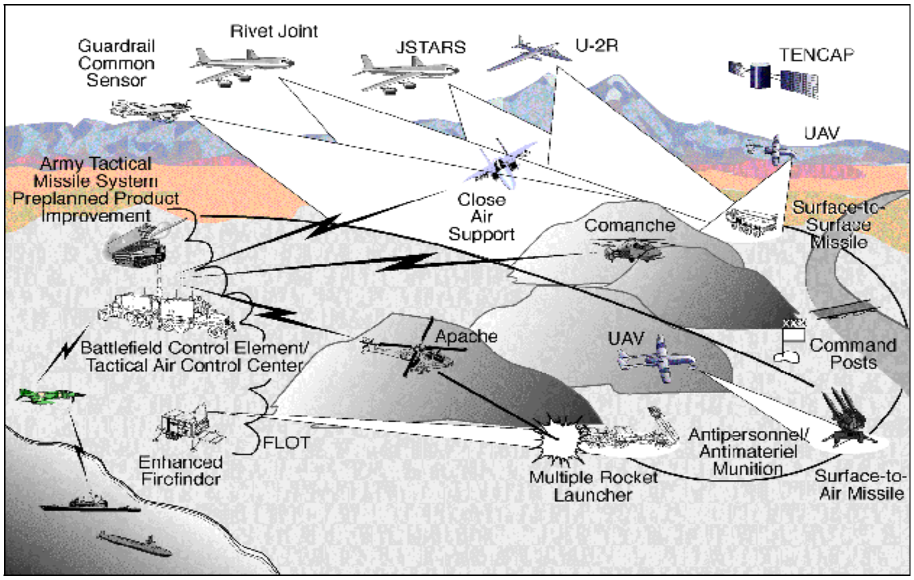

Figure 4. A Current Conception of Standoff Precision Strike

C. Naval Stealth and Standoff Precision Strike

Stealth and standoff precision strike development proceeded in the Navy largely independently from the Air Force and the Army. This history provides another view of both the opportunities and difficulties associated with developing and implementing disruptive capabilities. Even though radical changes to ship design and function have been very difficult to implement, DARPA has been able to stimulate new ideas that have ultimately been incorporated.[48]

Starting in the 1970s, DARPA and the Navy undertook a series of surface ship conceptual programs aimed at modernizing naval combat. The initial project, Sea Shadow, focused on applying stealth concepts from the F-117A acquisition program. DARPA then became involved in the Navy's 21st Century Surface Combatant (SC-21) development effort.[49] As part of SC-21, DARPA and the Navy conceived (but never

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48 Contractors have long joked that nothing can be used on a Navy ship that has not been certified, and nothing can be certified until it has been used on a Navy ship. However, disruptive ship concepts, such as nuclear submarines and the Aegis, have been implemented.

49 The Navy planners began developing operational requirements for the 21st Century Surface Combatant in the mid-1990s. The Joint Requirements Oversight Council (JROC) approved the SC-21 Mission Need Statement (MNS) in September 1994. Required capabilities called out in the MNS included: Power Projection; Battlespace Dominance; Command, Control and Surveillance; Joint Force Sustainment; Non-combat Operations; and Survivability/Mobility. In January 1995 the Defense Acquisition Board (DAB) gave approval to Milestone 0 for SC-21 Acquisition Phase 0 (Concept Exploration and Definition).

built) two concept ships—Arsenal Ship and DD-21, now termed DD-X—aimed at testing new technology, operating concepts, and acquisition methods. 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.

1. Sea Shadow

The principal objective of Sea Shadow was to evaluate the application of stealth technology to surface vessels. It also served as a tool for integrating and evaluating ship control systems, structures, automation for reduced manning, seakeeping, and signature control.[50] Like the F-117A, Sea Shadow began in 1978 as a highly classified program in the Lockheed Skunk Works. Based on stealth developments for the F-117A, as well as input from a company engineer who was aware of a catamaran-type ship that the Navy had built experimentally, Lockheed's Ben Rich presented the idea for a stealth ship to Under Secretary for Research and Engineering William Perry. Rich suggested they could test several stealth-related technologies on the ship. Perry agreed and ordered DARPA to authorize a study contract.[51] This small contract was aimed at developing a workable model catamaran and testing it against Soviet X-band radar.

The Lockheed team developed a model with a pair of underwater pontoon-type hulls with twin screws. (The eventual ship would be powered by diesel-electric propulsion with counter-rotating propellers.) The prototype resembled the stealth fighter with a series of flat planes at 45-degree angles (see Figure 5). The "A-frame" design of the hull minimized the ship's radar signature and reduced the surface area of the ship coming in contact with the water, hence reducing wake. Careful shaping of the pontoons and the propellers further reduced noise and wake.[52] The model had good stability in rolling seas.

On reviewing the initial test data, Perry ordered the Navy to fund construction of a prototype stealth ship. The mission of this ship would be to provide a forward-deployed defense against anti-ship missiles aimed at a carrier task force. Perry was adamant about proceeding, but the Navy was highly resistant, due both to the cost of the prototype and the perceived threat to other Navy ship building programs. In a meeting with the Chief of

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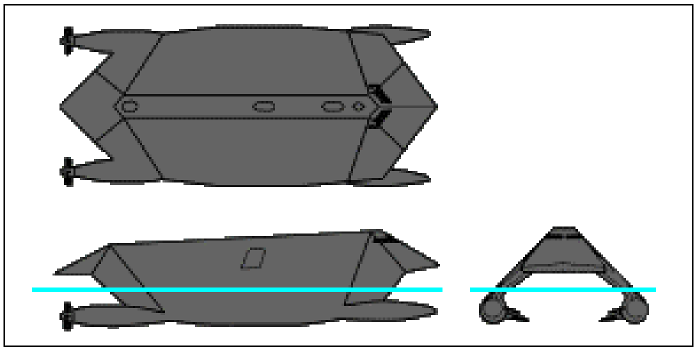
50 The US Navy, "Navy Fact File," <www.chinfo.navy.mil/navpalib/factfile/ships/ship-sea.html>.

51 Ben R. Rich and Leo Janos, *Skunk Works* (New York: Back Bay Books, 1994), p. 273.

52 Ibid., p. 274.



Source: Federation of American Scientists Website, <http://www.fas.org/man/dod-101/sys/ship/sea_shadow.htm>

Figure 5. Sea Shadow Schematic

Naval Operations, Admiral Hayward, Perry answered the Navy's reluctance by stating, "Admiral, we are going to build this ship. The only question is whether the Navy is going to be part of it."[53] Perry addressed Navy budget concerns by keeping funding stable for other Navy ships.

The Sea Shadow measured 70 feet wide and was constructed in modules in several shipyards and then assembled inside a huge submersible barge. Made of very strong welded steel, it displaced 560 tons. The ship initially had only a four-man crew: commander, helmsman, navigator, and engineer.[54] Over time, crew size increased to 24 people, which was still far less than on existing Navy ships.[55] Once constructed, the barge containing the Sea Shadow was towed to Long Beach to begin tests off Santa Cruz Island. All tests were at night against the most advanced Navy hunter planes. Rich reported 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.[56]

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53 Interviews with William Perry, Stanford, CA, June 7, 2001, and with Robert Fossum, Austin, Texas, February 7, 2002.

54 Rich and Janos, *Skunk Works* (New York: Back Bay Books, 1994), p. 277.

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

56 Rich and Janos, *Skunk Works* (New York: Back Bay Books, 1994), p. 279.

The tests were conducted for over 2 years and, by all indications, the Sea Shadow continued to perform well.[57] However, when the next administration came into office, the OSD Comptroller reduced funding for the DDG-51 Destroyer in the following year's budget request. The Navy interpreted this move as redirecting funds to pay for Sea Shadow. In response, Admiral Hayward cut the program out of the Navy's budget. (Under Secretary Perry was no longer in office to protect it.) Sea Shadow was deactivated in 1987 but then reactivated in 1993 for additional equipment testing. Its was once again deactivated in 1994 but again reactivated in 1999 in anticipation of using it to test automation and survivability technologies and support risk reduction efforts for DD-21.[58] Many of these technologies were eventually applied to Navy ships, but the Sea Shadow itself was never included in the fleet.

2. Arsenal Ship

The development of Sea Shadow had begun with the idea of defending the US. fleet on the high seas in a US-Soviet encounter. The Arsenal Ship concept was aimed at supporting the Navy's new post-Cold War vision of littoral conflict. A 1993 Navy study concluded that the new situation "is 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."[59] In contrast, after the Cold War, the Navy report stated:

> …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.

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57 Ibid. For a more restrained but still supportive view, see Paul A. Chalterton and Richard Paquette, "The Sea Shadow," pp. 296–308.

58 Federation of American Scientists, "Military Analysis Network, US Navy Ships—*Sea Shadow*," <www.fas.org/man/dod-101/sys/ship/sea_shadow.htm>.

59 US Navy. (Sept. 1992) *…From the Sea: Preparing the Naval Service for the 21st Century* (Washington DC: Pentagon).

The Arsenal Ship was intended to be a floating weapons platform for projecting naval power ashore—essentially a sea-based precision strike platform. A forward observer located somewhere on shore could call in the fire, select the type of munitions (missile or gun), and direct it on the target from his location.[60] 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."[61]

The Arsenal Ship concept threatened the traditional role of naval aviation in shore engagements as well as the role that Air Force bombers were carving out for themselves in the post-Cold War period (e.g., Global Reach). It had only mixed support among the top echelon of the uniformed Navy. Not only was it suspect among aviators, who saw it as a threat to the aircraft carrier, but the estimated program costs placed it in competition with other important Navy programs. There were also serious concerns about the ship's survivability. But the concept had the strong support both of the Chief of Naval Operations, Admiral Mike Boorda, and of John Douglass, Assistant Secretary of the Navy for Research, Development and Acquisition. (Douglass had previously been an Air Force officer heading the Precision Guided Munitions Office.)

Boorda and Douglass turned to DARPA to help implement the concept, as well as to provide a complementary source of R&D funding.[62] DARPA Director Larry Lynn was intrigued by the possibility that the ship, having a very small crew or perhaps none, might be built in such a way 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.[63] However, after further discussions, DARPA did become involved and a Memorandum of Agreement was signed.

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60 Robert S. Leonard, Jeffrey A. Drezner, and Geoffrey Sommer, *The Arsenal Ship Acquisition Process Experience: Contrasting and Common Impressions from the Contractor Teams and Joint Program Office,* Document MR-1030-DARPA (Santa Monica, CA: Rand Corporation, 1999).

61 Katherine McIntire Peters, *Government Executive,* "Ship Shape," 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).

62 Interview with John Douglass, February 5, 2002.

63 Ibid.

The Memorandum of Agreement laid out several technological and acquisition objectives for Arsenal Ship. In order to deliver large numbers of munitions to support ground forces early in an engagement, the ship would have to be forward deployed and under control of the theater commander. Hence it would require secure communications, reliable data linkages, and a remote munitions targeting and launch system. It would also need to have a low radar signature to be survivable. Acquisition goals included a total development-to-deployment timeline of 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.[64] These goals overlapped many of the development goals of the Sea Shadow.[65] For instance, the demonstration program was required to show that production ships of this class could operate on a 90-day mission, could have the communications and data links necessary for the CONOPS, could salvo three Tomahawk cruise missiles in 3 minutes, and could allow remote "digital call for fire" from the field commander.[66] DARPA had already developed the required communications and data systems through its Common Data Link for Sea Shadow and UAVs.

DARPA was given responsibility for leading the program in its early phases to "take advantage of its Section 845 Other Transaction Authority (OTA), and to facilitate transfer of its innovative business practices to the Navy acquisition community."[67] The use of Other Transaction Authority allowed the use of relatively few, broad performance characteristics and assignment of full design responsibility to the competing contractor teams. As a result, the government program office was kept small, and the contractor would be free to apply modern, efficient management practices in pursuit of the affordability goals.[68]

The DARPA Program Manager (PM) was responsible for developing a program plan that included major decision milestones, as well as a plan for transitioning the program from development to acquisition. A steering committee composed of DARPA and Navy personnel approved the initial program plan, conducted quarterly reviews to

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64 Compiled from: Alan Abramson. *The Arsenal Ship Measures Up to Joint Vision 2010* (Newport, RI: Naval War College, November 7, 1997), p. 4; Federation of American Scientists, "Military Analysis Network, US Navy Ships—Arsenal Ship," <www.fas.org/man/dod-101/sys/ship/arsenal_ship.htm>; and Center for Defense Information, *Arsenal Ship*, <www.cdi.org/issues/naval/arsenal.html>. Also see Leonard et al., *The Arsenal Ship*.

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

66 Memorandum of Agreement – Joint Navy/DARPA Program.

67 Leonard et al., *The Arsenal Ship*, p. 7.

68 Ibid.

assess progress, and provided guidance to the PM. A top-level DARPA and Navy Executive Committee was established to review the program at major decision milestones, to evaluate the validity of program cost thresholds, and to provide redirection as necessary.

In July 1996, six industry teams were awarded $1 million each to generate conceptual designs for Arsenal Ship and proposals for follow-on development. Three teams—a mix of Navy shipbuilders and defense firms with electronic and weapons expertise—received follow-on contracts in January 1997. The plan was to select one of the three teams to complete a detailed design of their proposed ship, build a prototype, undertake performance testing and evaluation, and, if successful, enter production. However, with the untimely death of CNO Boorda on May 16, 1996, Arsenal Ship lost a strong advocate in the Navy. Three months after the three teams were selected, the Navy informally announced a change in program focus, designating Arsenal Ship a Maritime Fire Support Demonstrator (MFSD). This change relegated Arsenal Ship to being a risk reduction demonstrator for the Navy's SC-21 program. Hence, Arsenal Ship, like Sea Shadow before it, was to be an at-sea technology test bed, not an independent development and production program. Furthermore, many of the advanced goals of the Arsenal Ship program were discarded at the behest of the naval aviation community.[69]

With the loss of top naval support, and with the Navy's shift in program focus, Congress cut the program's funding.[70] The Secretary of the Navy announced on October 24, 1997, that the Arsenal Ship program was canceled.[71] 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 FY98, which was a direct result of the Navy's poorly articulated and ambiguous legislative strategy for the Demonstrator."[72] Nonetheless, many the technologies developed for Sea Shadow and Arsenal Ship—stealth, automation to reduce manning, robust data links, and new

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69 Correspondence with Larry Lynn, June 2002.

70 Members of the House Armed Services Committee were not persuaded about the requirement for Arsenal Ship and questioned its cost-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.)

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

72 Leonard et al., *The Arsenal Ship*, p.84.

propulsion systems—were incorporated into the DD-21 and SC-21 programs.[73] Arsenal Ship PM Captain (later Admiral) Hamilton was selected to move to the DD-21 Program from Arsenal Ship.

3. DD-21 Zumwalt-Class Destroyer

The DD-21 was to be the first in the Navy's SC-21 Program, a family of surface combatant ships 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, similar to those considered for Arsenal Ship, to provide precise firepower at long ranges in support of forces ashore. DD-21 could either operate independently or as 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, (and) cutting-edge survivability features, such as in-stride mine avoidance."[74] DD-21 was also to be developed under a cost-driven strategy with a production cost goal of $650/$750 million for the fifth ship and an operating and support cost goal of $2,700 or less per hour. To do so, DD-21 would operate with a crew of 95. The ship's advanced gun system (AGS) would use GPS guidance to obtain accurate sustained fire at long ranges from a 155 mm gun. AGS would be fully automated and unmanned.[75]

Figure 6 illustrates the mission tasking that would be assigned to DD-21s. Like Arsenal Ship, DD 21 was planned to have a standoff strike capability and respond to requests for fire from troops ashore through a variety of target identification and communications systems.

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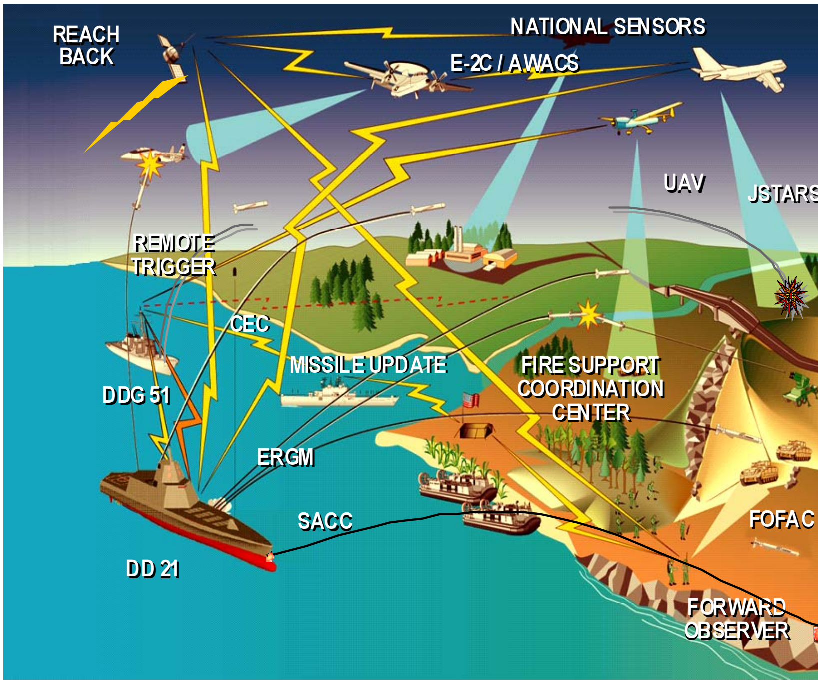
73 Interview with Admiral Charles Hamilton, January 22, 2002.

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

75 Federation of American Scientists, "Military Analysis Network, US Navy Ships—*DD 21 Zumwalt*," <www.fas.org/man/dod-101/sys/ship/dd-21.htm>.



Source: "DD 21 Modeling and Simulation Vision," briefing by Thien Ngo for Sarah Fidd, PMS500TV, DD 21 Program Office, March 7, 2000, downloaded 2/1/03 at <www.amso.army.mil/topic/fcs/mar-wkshp/dd21.ppt>.

Figure 6. DD-21 Operations

In November 2001, the Navy announced its intent to 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."[76] 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 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.[77]

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

77 Ibid.

The announcement further stated that the Navy would continue to review the program and would select 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.

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 an 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.

D. Intelligence, Surveillance, and Reconnaissance

A third aspect of the emerging RMA is fundamental improvement in the availability and use of information for planning and conducting military operations. Operation Desert Storm demonstrated new capabilities for "situation awareness," distributed real-time decision making, and adaptability. Numerous intelligence, surveillance, and reconnaissance (ISR) systems aboard satellites, aircraft, and unmanned aerial vehicles (UAVs) located both fixed and hidden targets, provided real-time data for precise targeting, performed battle damage assessment, and helped coordinate 500,000 widely dispersed soldiers, sailors, and airmen.[78] Many of these capabilities can trace their history to DARPA investments in ISR components and systems. ISR investments have been an enduring core area of DARPA research since its inception, yielding a broad range of component and subsystem breakthroughs. These include phased-array, synthetic-aperture, foliage-penetrating, and over-the-horizon radars; uncooled infrared cameras; and high-bandwidth, anti-jam data links and communication

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78 "Drones (RPVs)" at <http://www.pbs.org/wgbh/pages/frontline/gulf/weapons/drones.html> Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey Summary Report* (Washington, D.C.: Department of the Air Force, 1993) as quoted in Col Edward Mann, "Desert Storm: The First Information War?" *Aerospace Power Journal*, 1994. Joint C4ISR Support Center, *Global Information Grid Support to CINC Requirements*, May 15, 2001, p. 45.

systems.[79] These systems have improved the fidelity of information and reduced the latency in the "sensor to shooter loop," particularly by making ISR capabilities available to tactical users. DARPA has also concentrated on developing crosscutting capabilities beyond the purview of a single Service.

ISR systems interconnect several interdependent subsystems including:

- *Sensors* to detect and monitor enemy and friendly forces
- *Platforms* to deploy sensors
- *Processing* to convert sensor data into coherent information and visualizations
- *Fusion* to provide integrated knowledge and intelligence at different levels of detail
- *Communications links* for dissemination of information and knowledge

During Desert Storm, for example, JSTARS [80] combined synthetic aperture radar (sensor) with moving target indication (processing) on an E-8 aircraft (delivery). Data were transmitted to ground stations (communications link) and consolidated with other information (fusion) at command centers to generate precise targeting information for attacking forces. Pioneer Unmanned Aerial Vehicles (delivery) carrying TV cameras and infrared detectors (sensors) sent real-time data (links) to shipboard computers (processing) which, combined with satellite data (fusion), was used to find and attack enemy ground forces.[81]

Early ISR systems were typically "national assets" controlled by intelligence organizations. In the late 1950s, the Central Intelligence Agency (CIA) took control of satellite reconnaissance from the Air Force, thanks in part to Eisenhower's desire to prevent military operational priorities from overly influencing national policy. Classification has been another reason for centralizing ISR capabilities in the intelligence community. Information about enemy capabilities—and especially the methods used to acquire that information—are closely guarded secrets. The National Reconnaissance Office (NRO) was established in late 1960 to centralize operations and reinforce high-level civilian control.[82]

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79 Richard Van Atta, Seymour Deitchman, and Sidney Reed, *DARPA Technical Accomplishments, Volume III,* IDA Paper P-2538 (Alexandria, VA: Institute for Defense Analyses), July 1991.

80 See page 21 for a description of JSTARS.

81 "Drones (RPVs)" at http://www.pbs.org/wgbh/pages/frontline/gulf/weapons/drones.html.

82 Greg Goebel, "Spy Satellites" at http://www.vectorsite.net/taspy.html.

Although the capabilities of national assets have improved dramatically over the years, their separation from operating forces, their centralized, hierarchical operating procedures, and classification issues have made it difficult to provide timely information to tactical commanders. Information needed by commanders and planners may be collected and processed in time, but it is often embedded in a stream of data that works its way through the system too slowly to be tactically useful.[83] If solicited from key individuals within the intelligence system, specific information can be extracted and forwarded hours-to-days faster than normal. An Air Force planner during Desert Storm cited an example of "normal time delays involved in getting information [through the formal system]:"

> We wanted a photo of a particular target. . . . [Brig Gen Buster C.] Glosson picks up the phone, calls [DIA Director Mike] McConnell, and we get the photo in about 4 hours. . . . Twenty-four hours later, about, he gets a photo from CENTCOM [US Central Command] or CENTAF/IN [Intelligence]. About 24 hours after that, 48 hours later, we get the same photo from CENTCOM/J-2 [Intelligence].[84]

In the Gulf War, operational planners regularly resorted to unofficial and informal arrangements outside the system.[85] Certain flying units formed their own battle damage assessment cells. Using gun-camera video and other information obtained outside intelligence channels, they bypassed the formal system almost entirely.[86]

The increasing use of precision weapons has also strained traditional ISR systems. Soon after Desert Storm, the director of the Defense Intelligence Agency explained the following:

> …in the past the identification of a specific targeted building sufficed. Today precision delivery capabilities require further identification—down to a particular room in that targeted building. This increase in the level of

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83 James R. Clapper, "Desert War: Crucible for Intelligence Systems," in Alan D. Campen, ed., *The First Information War: The Story of Communications, Computers and Intelligence Systems in the Persian Gulf War* (Fairfax, Va.: AFCEA International Press, 1992), pp. 81–85, as quoted in Col Edward Mann, "Desert Storm: The First Information War?" *Aerospace Power Journal*, 1994.

84 Lt Col Dave Deptula, Washington, D.C., transcript of interview with Lt Col Suzanne B. Gehri, Lt Col Richard T. Reynolds, and Col Edward Mann, December 12, 1991, Desert Story Collection, US Air Force Historical Research Agency, Maxwell Air Force Base, Alabama, pp. 91–92, as quoted in Col Edward Mann, "Desert Storm: The First Information War?," *Aerospace Power Journal*, Winter 1994.

85 Keeney and Cohen, *Gulf War Air Power Survey,* pp. 129–130.

86 Mann, *Desert Storm,* p. 14.

> targeting detail demands exacting geo-positional data, near-real time imagery, and fused all-source intelligence.[87]

The following sections highlight DARPA's role in two types of ISR systems that support tactical users: UAVs and small satellites. These systems were conceived to provide commanders in the field with the type of ISR capabilities only available at the time from large systems controlled by national leadership. They also enabled entirely new types of ISR capabilities. DARPA took the lead role in developing novel capabilities in both areas but faced major challenges in reducing them to practice because they challenged existing operational motifs and competed with organizations interested in incrementally improving existing capabilities. Thus, the history of UAVs and small satellites illustrates the kind of problems involved in transitioning disruptive capabilities.

1. Unmanned Aerial Vehicles

UAVs encompass a range of vehicles including balloons, gliders, rotorcraft, and multiengine aircraft.[88] We focus here on powered UAVs with either onboard or remote guidance. There are three broad groups of such UAVs:

- *High-Altitude/Long Endurance*. Considered as substitutes for manned aircraft such as the EC-121 and U2, these large airframes can fly long-range at high-altitudes with relatively heavy payloads.
- *Medium-Scale*. These UAVs perform low-altitude reconnaissance, electronic warfare, and strike. Weighing between 500 and 5,000 pounds, they can fly quickly and maneuver in adverse weather conditions, day or night.
- *Tactical or "Mini" UAVs*. These are essentially scaled up model airplanes characterized by low-speed, low-altitude, limited endurance, and small payloads. They are designed to be cheap and easily maintained and, hence, plentiful.[89]

The desire to reduce the cost in men and aircraft during the Vietnam War focused attention on remotely piloted vehicles, a form of UAV, for tactical reconnaissance

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[87] James R. Clapper, Jr., "Challenging Joint Military Intelligence," *Joint Forces Quarterly*, Spring 1994, p. 94.

[88] 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 into the larger UAV term. It is useful to note that one major difference between UAVs and RPVs is that RPVs have been defined by the DoD as "unmanned, powered, airborne vehicles which are controlled by man." (Statement of Mr. Robert Parker before the Senate Armed Services Committee, 1976 (Y4.AR5/3:P94/6/976/pt 10).

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

missions deep behind enemy lines.[90] The Firebee and variants, medium-scale RPVs, provided surveillance.[91] A rotorcraft RPV called SNOOPY, developed by the Navy and improved through several DARPA projects, carried various payloads: a low-light-level TV system, communications and guidance systems, a moving target indication radar, a hypervelocity gun, a laser designator rocket system, and other weapons. Two DARPA experimental rotary systems designed to demonstrate remote target acquisition (NITE PANTHER) and standoff precision strike (NITE GAZELLE) at ranges over 100 nautical miles were both used successfully.[92]

In 1971, DDR&E Dr. John Foster, a model airplane enthusiast, recommended that the DARPA RPV programs move from expensive and complicated helicopter platforms such as NITE GAZELLE and instead focus on lightweight, inexpensive model airplane technology. After a 1971 Defense Science Board study of RPVs submitted a positive report on RPV progress, DARPA initiated the Mini-RPV Program to "evolve new Service options for low-cost, low speed, small, unmanned aircraft for missions such as reconnaissance, target acquisition, target laser designation, or target strike."[93] DARPA's role was critical to the overall RPV development and fielding effort. Testifying in 1974, Mr. Robert Heeber, Deputy DDR&E, observed, "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."[94]

The initial RPVs resulting from DARPA's effort—Praerie and Calere—had exchangeable modular payloads. Weighing 75 pounds and powered by a modified lawn mower engine, they could carry a 28-pound payload for 2-hours. The Praerie carried a daytime TV and a laser target designator. Calere carried a lightweight forward-looking infrared (FLIR) detector and laser target designator combination. The Praerie was

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90 Congressional Budget Office. *Options for Enhancing the Department of Defense's Unmanned Aerial Vehicle Programs* (Washington, DC: Congressional Information Service, 1998), p. 13.

91 US Army Aviation Center: *Unmanned Aerial Vehicle Study*, Ft. Rucker AL, 1993.

92 Van Atta et al., *DARPA Technical Accomplishments,* Vol. I, p. 28-3.

93 George Heilmeier, Testimony before the Senate Committee on Armed Services, FY78 Authorization for Military Procurement, Research and Development and Active Duty, Selected Rescue, and Civilian Personnel Strengths, Research and Development, March 17, 23, 29–31, 1977, CIS 77-S201-30, p. 6240.

94 US Congress, testimony before the Senate Armed Services Committee, March 1974, Y4.Ar5/3:P94/6/1975/pt. 6. p. 3037.

intended to be an austere system with a mass production cost of $10,000 each. The first flight of Praeire I occurred in 1973 as part of a joint DARPA-Army program. DARPA subsequently developed the Praerie II, Calere II, and Calere III with reduced radar and IR signatures, improved sensors, electronic warfare capabilities, FLIRs, laser designators, and the ability to fly for up to 6 hours.

In 1977, DARPA Director George Heilmeier reported to Congress that DARPA had succeeded in developing mini-RPVs to the point that the DARPA mini-RPV program would be ending:

> 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 (integrated communications/navigation system) and loiter mine developments in FY1978.[95]

Problems in Transitioning Mini-UAVs

Although various RPV transition efforts looked very promising in 1977, the actual path to deployment would prove long and difficult. The end of US military involvement in Vietnam led to a massive reduction of US military forces, including elimination of Air Force RPV organizations in 1976. Firebee-derived RPVs for flak suppression, chaff dispensing, target designation, and weapons delivery roles were successfully demonstrated, but these expanded roles were never performed operationally. Air Force interest shifted to cruise missiles.

The Army's Aquila Program emerged out of the initial DARPA-Army collaboration on Prairie. This program devolved into what at best could be termed "an acquisition nightmare" that is almost universally acknowledged as an example of what not to do in an advanced technology acquisition program.[96] Aquila began as a System Technology Demonstrator (STD) in 1974. It sought to demonstrate the capability to

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95 George Heilmeier, CIS 77-S201-30.

96 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).

perform reconnaissance, acquire and identify targets, and survive. As a demonstrator project it was "loosely spec'd" and built using largely commercial components.[97] The program succeeded in showing that a reconnaissance UAV for meeting tactical Army needs was achievable. An acquisition program was subsequently initiated in 1978, and full scale development began in 1979. 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.[98] However, by the time the Army abandoned the program in 1987 due to cost, schedule, and technical difficulties, the Aquila Program had cost over $1 billion, and future procurement costs were expected to have been an additional $1.1 billion for 376 aircraft.[99]

The original mission and design for Aquila was relatively simple, yet tactically useful. It was to be a small, propeller-driven aircraft that could be operated by four soldiers, providing ground commanders with real-time battlefield information about enemy forces located beyond ground line of sight.[100] But as full-scale development began, more missions and requirements were added. Considerable confusion developed over the specifics of how Aquila would be deployed and what branch within the Army ought to own the capability. Should it belong to the artillery for deep targeting, to intelligence for general intelligence gathering, or to field commanders (divisions or Corps) for intelligence and operational planning?[101] Ultimately the lack of cooperation among these Army branches and the inability to decide on the mission undermined the Aquila program.[102] With the escalation in cost and the delays in the program, Aquila was canceled in 1988, having "failed to field a system the Army sorely needs."[103] By the time of termination, the

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97 Ibid., p. 3.

98 US General Accounting Office, *Unmanned Aerial Vehicles: DOD's Acquisition Efforts,* Testimony, GAO/T-NSIAD-97-138 (Washington, DC: Government Printing Office, 1997) p. 2.1.

99 Ibid.

100 Ibid.

101 Knox, *Gladiators and Spectators,* pp. 4–8. His review shows how the Army's AVSCOM loaded Aquila with requirements based on manned aviation, while the Field Artillery School added target acquisition requirements, which were much more technically demanding than the initial reconnaissance mission. Added to these were requirements for high-level jam resistance, etc., which ran counter to the original concept of an austere, low-cost system. The Army meanwhile fought to keep the program costs below $100 million, which became increasingly unrealistic as program requirements exploded.

102 Interview with General Louis Wagner, August 9, 2002.

103 Brigadier General David R. Gust, Program Executive Officer, Communications Systems, US Army, "A Message for the Battle Labs: Last Three Years of Aquila and How the Army Failed to Field New Technology," no date.

list of avionics and payloads required by various Army organizations had grown well beyond the carrying capacity of the small aircraft.[104] (Requirements growth and divided responsibility continue to inhibit Army procurement of UAVs to this day.)

Meanwhile, US combat operations in the early 1980s persuaded Secretary of the Navy Lehman of the need for an on-call, inexpensive, unmanned, over-the-horizon targeting, reconnaissance, and battle damage assessment capability for local Navy commanders. In July 1985, Lehman directed the acquisition of UAV systems based on nondevelopmental technology. A competitive fly-off was conducted, leading to procurement in December 1985 of two Pioneer systems, an Israeli system based on the Praeire.[105] Initial deliveries were made in July 1986, and the aircraft were deployed on the battleship USS Iowa in December 1986. During 1987, three additional systems were delivered to the Marines, where they were operationally deployed onboard amphibious assault vessels and with land-based units. All of these UAVs were subjected to accelerated testing.

With the termination of Aquila, the Army was left with an unmet need for long-range artillery spotting. Based on the Navy's success with Pioneer, a joint service program was formed. As a result, the Army fielded Pioneer in 1990.[106] In 1991, Pioneers flew nearly 300 reconnaissance sorties at the beginning of operation Desert Storm.[107] In one of the more unusual events of the war, a group of Iraqi soldiers attempted to surrender to a Pioneer flying low over the battlefield by waving white flags at its miniature TV camera. (Perhaps they knew that it had a real-time link to a warship that could quickly respond with artillery fire.)

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.[108] It also worked on enabling technologies such as miniature sensors, anti-jam data links, the Integrated

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104 General Accounting Office, *Unmanned Aerial Vehicles,* p. 2.1.

105 Israel obtained DoD approval to buy several Praeire II B systems in 1977. From these systems it developed its Mastiff RPV, later the Scout and then the Pioneer.

106 "History of Pioneer," <www.aaicorp.com>.

107 Ibid., p. 184 and 195.

108 US Congress, testimony before the Senate Armed Services Committee, April 1974, Y4.Ar5/3:P94/6/1975/pt. 6. p. 3036.

Communications-Navigation System (ICNS), and classified technologies for Intelligence agencies.

From 1980 to 1982, the DARPA TACIT 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. TACIT 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.[109] This program successfully demonstrated very long-endurance and high-altitude operation but failed to receive support to move into acquisition.

In 1984, DARPA initiated the Amber program. The Amber concept 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.[110] Subsequently, DARPA funded Amber with the aim of creating a long endurance, low observables 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.

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[109] Interview, Charles Heber, February 27, 2002.

[110] 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.

In the midst of the Amber program, Congress expressed concern about the failure of the Services to deploy UAVs and about the direction of UAV development in general. The Conference Report for the Department of Defense Authorization Act of FY1987 contained a request asking the DoD to submit a UAV Master Plan with its FY1988 budget request. The House Armed Services Committee further recommended that the Assistant Secretary of Defense for Command, Control, Communications, and Intelligence merge all the Service programs for all classes of UAVs.[111] The FY88 Defense Appropriations Act then consolidated all nonlethal UAV developments into a Joint Program Office (JPO) in the Office of Secretary of Defense, transferring 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. 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.[112] Moreover, Dr. Karem 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 first cut, and then the program was terminated. LSI

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[111] US General Accounting Office, *Unmanned Vehicles: Assessment of DOD's Unmanned Aerial Vehicle Master Plan,* Report NSIAD-89-41BR, (Washington, DC: Government Printing Office, 1989).

[112] 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.

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 bogged down in increasing requirements from the Army and the Navy, resulting in an expensive system that did not perform any particular mission well.[113]

Third Generation Efforts

Following the Gulf War, a Defense Science Board (DSB) study highlighted serious deficiencies in airborne 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.[114] The regional combatant commanders expressed a need for long endurance surveillance for counterdrug and peacekeeping missions.[115] 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.[116]

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 Tier III was a classified technology development program for a stealthy, very long endurance capability. Top OSD and intelligence community

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[113] Ibid.

[114] Interview with Charles Heber, February 26, 2002.

[115] Interview Robert Williams, March 26, 2001.

[116] Hundley, *Past Revolutions, Future Transformations*, p. 6.

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. They initiated an internal review of all airborne and satellite surveillance in mid-1993, 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[117]
- 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.[118]

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117 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.

118 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,[119] was designed for near-real-time reconnaissance, surveillance, target acquisition, and battle damage assessment in all weather conditions.[120] 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.[121] 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.[122] 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)[123] 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.[124] Sensor data is relayed over

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[119] Predator can be traced all the way back to DARPA's work in Praerie. Israel purchased Praerie II technology, built on it, and used it effectively in combat. The technology and operational concepts came back to the US through Abraham Karen, 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.

[120] Congressional Budget Office, *Options for Enhancing the Department of Defense's Unmanned Aerial Vehicle Programs* (Washington, DC: Congressional Information Service, September 1998), pp. 14–15.

[121] Ibid., p. 20.

[122] 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.

[123] Because Global Hawk is a classified program, its development history is harder to discern. It appears to go back to a 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.

[124] Ibid.

line-of-sight (X-band) and/or beyond-line-of-sight (Ku-band SATCOM) data links to its Mission Control Element (MCE).[125]

On the Global Hawk program, DARPA pioneered several new acquisition methods to speed technology transition.[126] 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 FY94 dollars). All other performance characteristics were stated as goals and could be traded to achieve the target price.[127]

Although the Global Hawk is still in an early acquisition phase, it was deployed in support of Operation Enduring Freedom in Afghanistan.[128] 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.[129]

Despite the recent enthusiasm for UAVs, many challenges remain. As late as 1997, some members of Congress were still skeptical about DoD's UAV acquisition process. For example, Representative Duncan Hunter stated, "It seems that over the last

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125 Office of the Secretary of Defense, *Unmanned Aerial Vehicles, Roadmap, 2000–2025*, US Department of Defense, 2000.

126 Rand Corporation, *Innovative Management in the DARPA HAE UAV Program*, MR-1054-DARPA, 1999, p. xiv.

127 Prepared statement of Mr. Charles E. Heber, Director, High Altitude Endurance Unmanned Air Vehicle Program Office, Defense Advanced Research Projects Agency, before the Senate Armed Services Committee and Subcommittee on Airland Forces, March 29, 1996. Unit costs reportedly have gone up to $15 million.

128 US Government 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.

129 Thomas G. Mahnken, "Transforming the US Armed Forces: Rhetoric or Reality," *NWC Review*, Summer 2001.

20 years we have spent billions of dollars developing a variety of [UAV] platforms, but for some unknown reason, there are precious few assets available in inventory."[130] Also, despite Predator's successful employment in Bosnia, Kosovo, Iraq, and Afghanistan, a report released in October 2002 from the DoD Office of Operational Testing and Evaluation found that the Predator is "effective but not without limitations and difficulties" (e.g., poor location accuracy, communications failures, and sensitivity to ice and rain) and "suitable, though reliability and maintainability problems persist."[131] One-third of the 60 Predators acquired to date have crashed, due to mishaps, weather, or losses over enemy territory.[132]

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. They 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.

2. Satellites

Traditionally, US space reconnaissance capabilities have been based on a small number of large, expensive systems that are vulnerable to single point failure. High system purchase costs, and operational costs in the billions of dollars per year, put great pressure on the intelligence community to search for alternatives. Since the mid-1980s, the concept of "lightsats"—a large constellation of smaller, less expensive satellites—has been explored. Lightsats could offer several advantages, including:

- Lower launch costs, due to reduced payload weight
- More frequent revisit times, due to a large constellation
- Improved global coverage, due to greater satellite distribution

130 Prepared statement of the Honorable Duncan Hunter, Chairman, Military Procurement Subcommittee before the House National Security Committee, Military Procurement Committee and Military Research and Development Subcommittee, April 9, 1997.

131 Thomas Christie, DoD Director of Operational Test and Evaluation, *Report on the Predator Medium-Altitude Endurance Unmanned Aerial Vehicle,* October 31, 2001, p. i.

132 Roxana Tiron, "Despite Doubts, Air Force Stands by Predator," *National Defense*, December 2001.

More importantly, lightsats could enable new mission capabilities, such as:

- Continuous deep observation of mobile targets
- 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 whose data is downloaded to national organizations for processing and forwarding to users)

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.[133] 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 and used it 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.[134]

Still, significant shortfalls in imaging capabilities became apparent during the Gulf War and later in the Balkan conflict. Satellite imagery coverage was not continuous, so Iraqi forces were able to move without detection by satellite in the periods between overflights.[135] In the Balkans, cloud cover impeded the detection and tracking of Serbian armored forces.[136] Finally, imagery collected by national systems often was not provided in usable forms to tactical commanders on timelines that would allow the information to be exploited.[137] This was particularly a problem for information concerning mobile forces.

Discoverer II (DII), a satellite radar demonstration program, was intended to address these issues. Based on DARPA-developed technologies for space-based radar (SBR) with Ground Moving Target Indication (GMTI) and Synthetic Aperture Radar (SAR) imaging capabilities, DII would seek to provide all-weather imagery for near-real-

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133 Office of Technology Assessment, *Affordable Spacecraft: Design and Launch Alternatives* (Washington, DC: US Government Printing Office, 1990).

134 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.

135 "Spy Satellites," <wsiwyg://24http://vectorsite.tripod.com/taspy.html.>

136 James T. Hackett, "Keeping Our Lead in Space," *Washington Times*, June 23, 2000, <www.cdiss.org/col00june23.htm>.

137 *Space News*, March 4, 1991, <www.islandone.org/SpencerAvLeakReports/AvWeek-910304.html.>

time reconnaissance of mobile and fixed targets, *provided directly to tactical commanders in a system that would be tasked by these commanders.* 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.

A 1997 DARPA-sponsored study proposed an initial concept for DII.[138] While holding the cost of satellites to less than $100 million each, the system intended to provide three new types of capabilities:[139]

- Deep, broad area, near-continuous, near-real-time, GMTI to allow tracking of adversary vehicles
- High-resolution (about 1 meter), three-dimensional SAR imaging to support precision targeting
- Tasking by joint task force commanders, who would directly receive downlinked data on both fixed and mobile targets

DII was intended to be a staged technology R&D program. In the first phase, industry would conduct detailed trade studies necessary to define a demonstrator system for the 2005 time frame and an affordable objective space-based radar system for the 2010 time frame. Concurrently, a risk reduction program would feed results into the demonstrator effort. If an affordable objective system were deemed achievable, Phase II would build and fly two satellites. That demonstration would show how an objective system could provide deep-look access into denied areas and near-continuous coverage from diverse look angles over the battlefield, complementing UAV imagery. It would allow the joint community to make an informed decision about full-scale deployment.[140]

Full deployment of an entire DII constellation of 24 satellites would provide a major improvement in ISR capabilities. SAR imaging 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 under certain circumstances. Tasking by theater commanders and a direct data link to them would provide a revolutionary improvement in responsiveness. Finally, DII would allow the US to take fuller advantage of the revolution

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[138] "Discoverer II (DII) STARLITE," <www.fas.org/app/military/program/imint/startlight.htm>.

[139] DARPA, February 2000 RDT&E Budget Justification (R-2).

[140] RDT&E Budget Item Justification Sheet (R-2 Exhibit), "Sensor and Guidance Technology, PE 0603762E, Project SGT-02," February 2000.

in munitions guidance.[141] Attacking targets with precision depends on knowing their locations with comparable precision to the munition's guidance system. For low-flying cruise missiles or aircraft, three-dimensional data is required for route planning. As planned, DII would provide three-dimensional geolocation information with an accuracy of roughly 1 meter.

The Air Force wanted DIIs to augment systems such as JSTARS, U-2 aircraft, and UAVs.[142] Perceived advantages of DII were more continuous access, direct and timely reporting to support targeting, and freedom from burdensome intelligence community security classifications and procedures. The space-based radar option also aligned with an Air Force corporate decision to move more surveillance and reconnaissance functions to space and to give increased priority to space-related research and development.[143] The Army was interested in exploring the feasibility and utility of delegating collection management authority to a corps commander, as well as in the type of imagery that could be made available.[144] From DARPA's perspective, DII involved high-risk technologies, necessitating an on-orbit demonstration.

Because DII was a risky, long-term program, DARPA did not view it as serious competition for the full range of NRO's planned Future Imagery Architecture (FIA) systems. NRO, however, believed that DII would compete with a segment of FIA. DII also highlighted a potential future conflict between the role of NRO and the Air Force's plans to migrate key surveillance and reconnaissance capabilities from aircraft to spacecraft.[145] One report noted:

> The exact implications of this vision of future military ISR needs for space reconnaissance are not totally clear because of uncertainties at this point

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141 John S. Foster and Larry D. Welch, "The Evolving Battlefield," *Physics Today*, December 2000.

142 Pamela Hess, "Air Force Standing by Decision Not to Reinstate JSTARS Production," *Inside the Air Force*, April 2, 1998.

143 Lieutenant General Gregory S. Martin, Principal Deputy Assistant Secretary of the Air Force (Acquisition), "Emerging Threats and Capabilities," Presentation to the Senate Armed Services Committee Subcommittee, April 1999.

144 "Space," *Army Science and Technology Master Plan* (Washington DC: Department of the Army, 1998).

145 Pamela Hess, "Starlite Shelved While USAF, NRO Work Out Roles, Redundancy Issues," *Inside the Air Force*, May 23, 1997.

over the relative roles of airborne reconnaissance systems, nonintelligence space surveillance systems, and space reconnaissance systems.[146]

An influential January 1998 DSB task force report on Satellite Reconnaissance reinforced this notion, pointing out that the roles and relationships of these organizations would have to be resolved. To allay NRO concerns that the DII concept would be redundant to the FIA, the DSB proposed establishment of a joint program office, co-sponsored by the Air Force, NRO, and DARPA.[147] This was done, and in April 1998, the program was formally named Discoverer II.[148] In a parallel effort, the Army committed to modify an existing tactical ground station to provide an interface for the ground force commander.

Despite the apparent resolution of organizational conflicts, DII experienced problems in Congress, which viewed DII as an acquisition program, not a demonstration. In June 1998, the House Appropriations Committee recommended elimination of DII funding because DoD had not provided the required notification for a major new start. Press coverage noted the absence of a formal requirements document for DII, as would be required if DII were an acquisition program.[149] These issues were overcome, however, and FY 1999 funding was provided. In February 1999, DARPA selected contractors for phase 1a of DII.[150] In September 1999, NRO also announced award of a contract to Boeing for development, launch integration, and operation of FIA.[151]

In the FY 2000 budget process, the House Appropriations Committee again expressed opposition to DII and recommended that the program be canceled.[152] A number of members of Congress then wrote in support of DII, noting that CINC SPACECOM had characterized it as his number one technology program.[153] Secretary

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146 *Defining the Future of the NRO for the 21st Century,* Report to Director National Reconnaissance Office, August 26, 1996. p. 8.

147 "Critical Intelligence," Inside *the Pentagon*, February 5, 1998.

148 "Discoverer II (DII) STARLITE," <www.fas.org/app/military/program/imint/startlight.htm>.

149 Gigi Whitley, "Citing Lack of Notification, Committee Deletes Discoverer II Funds," *Defense Information and Electronics Report,* June 26, 1998.

150 "Discoverer II Contractors Selected," *Air Force News*, February 22, 1999.

151 National Reconnaissance Office Press Release, September 3, 1999.

152 SSgt. Michael Dorsey, "Funding Cut Threatens Space Project," *Aerotech News and Review,* August 27, 1999.

153 Letter from Senator Kyl and other Senators to Senator Ted Stevens, *Inside the Air Forre,* July 14, 2000.

Cohen mentioned DII in his letter accompanying DoD appropriations appeals.[154] The full Congress restored funding of $40 million (a reduction of $65.8 million from the request) under the restriction that this funding could be used only to complete the Phase I study portion of the program and to cover associated program management costs.[155] Phase Ib contract awards for DII were subsequently announced in May 2000.[156]

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 and directed the Secretary of Defense to prepare an SBR roadmap by May 1, 2001, addressing:

- The operational requirements for space-based GMTI, Digital Terrain Elevation Data (DTED), and SAR capabilities
- The relationship of an SBR system to other current and planned air and space-based assets
- The technologies needed to enable an affordable and operationally effective SBR system
- Why a pre-acquisition, space-based technology demonstrator would be cost-beneficial[157]

However, during the FY 2001 defense appropriation process, House appropriators yet again expressed opposition to the program. Senate appropriators supported continuation, but the House decision to terminate the program was sustained in the appropriations conference:

> 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

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[154] Cohen Letter Accompanying DoD Appropriations Appeal Package, *Inside the Army,* July 17, 2000.

[155] Conference Report on H.R. 2561, H9813, October 8, 1999.

[156] "TRW/Northrop Grumman Team Awarded Discoverer II Contract Option for Competitive Concept Definition," Press Release, TRW, Inc., May 5, 2000.

[157] United States House of Representatives, Report 106-945.

> 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.[158]

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).[159] The National Space Architect initiated a related multi-service, multi-agency effort to develop an SBR Roadmap.[160]

Additionally, an 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 Earth on a near-continuous basis.[161] 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.[162] 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 ISR system no later than fiscal year 2010. 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

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158 United States House of Representatives, Report 106-644.

159 United States Air Force Fact Sheet, "Space-Based Radar (SBR)," June 2001, <www.losangeles.af.mil/smc/pa/fact_sheets/sbr.htm>; and Amy Butler, "Rapid-Deploy Space-Based Radar Could be Launched in Fiscal Year 2006," *Inside Missile Defense*, March 20, 2002.

160 General Ralph E. Eberhart, USAF, Commander in Chief, North American Aerospace Defense Command and United States Space Command, Testimony to United States Senate Arms Services Committee, Strategic Subcommittee, July 11, 2001, p. 13.

161 RDT&E Budget Item Justification Sheet (R-2 Exhibit). Budget Activity 05-Engineering and Manufacturing Development. PE 0604251F, "Space-Based RADAR EMD," June 2001.

162 United States Air Force Fact Sheet, "Space-Based Radar (SBR)."

2002 budget request. The President's Budget Estimates for fiscal year 2003 included $91 million for space-based radar.[163]

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 is difficult to do for a disruptive capability that addresses needs in a new way, as there is 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.

IV. CONCLUSIONS

A. Insights from the Reviewed DARPA Programs

DARPA has been instrumental in the development of a number of technologies, systems, and concepts critical to the RMA. It did so by serving as DoD's corporate research activity, reporting to the top of the organization, with the flexibility to move rapidly into new areas and explore opportunities that held potential for "changing the business." DARPA acted as a catalyst for innovation by defining research programs linked to DoD strategic needs, seeding and coordinating external research communities, and funding large-scale demonstrations of disruptive concepts. In doing so, the DARPA programs described in this study presented senior DoD leadership with opportunities to develop disruptive capabilities. With consistent senior leadership support, typically from the highest levels of the Office of the Secretary of Defense and the Services, development of these disruptive capabilities transitioned into acquisition and deployment. Otherwise, only the less disruptive elements moved forward. Disruptive concepts also tended to progress further if they:

- Were focused on a small set of clear, high priority missions
- Did not compete directly with the missions of existing large platforms
- Involved only a single Service
- Did not require multiple contractors for integration
- Could be run as classified programs

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[163] Vernon Loeb, "New Weapon Systems are Budget Winners," The *Washington Post,* February 8, 2002, p. A29.

- Could be brought to an acquisition decision during the tenure of the initial high-level decision makers.

To illustrate, Table 1 compares the F-117A, UAVs, and ASSAULT BREAKER along these dimensions. The text below elaborates on these observations in these cases and in the others described in this study.

In championing stealth, DARPA harnessed industry ideas and funded the considerable engineering work required to enable top OSD and Service leadership to proceed with confidence with a full-scale acquisition program. The F-117A was a clear success: a disruptive capability that proceeded from idea to initial deployment in just 5 years. Low-observable aircraft had been built before but were not pursued for combat applications. DARPA provided a venue for industry to explore new systems designs. It is doubtful that the Service R&D process would have embraced and pushed this radical concept into multiple applications. With support from OSD leadership, DARPA set out priorities and obtained funding for the considerable engineering work needed to demonstrate the HAVE BLUE proof-of-concept system, which enabled top OSD and Service leadership to proceed with confidence. Once persuaded, OSD and Service leadership provided funding and support for a full-scale acquisition program. OSD leadership kept the F-117A program focused on a limited set of initial, realistic goals and worked with Congress to protect its budget. The F-117A was developed and fielded under the highest levels of secrecy, leading to a "secret weapon" capability—exactly what DARPA and top DoD leadership had envisioned.

Table 1. Comparison of F-117A, UAVs and ASSAULT BREAKER

	F-117A	UAVs	Assault Breaker
Mission Clarity	Relatively focused, high-priority mission	Multiple missions, ops. concepts & tech. needs	Change in mission need during development
Mission Competition	Focused on missions that existing aircraft could not perform	Overlapped large platform missions	Substitute for a core mission of large platforms
Jointness	Attached to single platform owned by individual service	Multiple platforms but single-service deployment	Intrinsically joint, requiring major changes in doctrine
Integration	District platform implemented sole-source	Multiple platforms but single contractor for each	Multiple contractors for each "system of systems" component
Openness	Secret and "black" (compartmentalized)	Mixed secret/black and open	Open
Timing	Brought to acq. decision during a single administration	Successful transition once top-level imprimatur given	Demonstration completed after initial decisionmakers gone

In standoff precision strike, DARPA worked for years on technologies for finding, precisely hitting, and destroying targets on the battlefield under a variety of conditions. Based on detailed threat definition studies, DARPA conceived and developed ASSAULT BREAKER, an intrinsically joint concept for a "system-of systems" that challenged existing operational concepts and organizational structures. While DARPA and the Services could have incrementally developed and linked pieces in a step-wise manner, the integration of these capabilities into an end-to-end system demonstrated a significant new capability for attacking tank echelons deep in enemy territory.

Through a number of mechanisms OSD tried to provide dedicated and sustained financial and organizational resources to implement ASSAULT BREAKER components. But the Service acquisition system dissipated and delayed the subsequent development programs, diluting the original vision for a joint capability. However, the success of various technology elements of ASSAULT BREAKER brought more attention to the possibilities for integrated standoff precision strike. Standoff precision strike capabilities are still evolving today, in some cases moving beyond the concepts DARPA promulgated and demonstrated. However, the terminally-guided precision munitions envisioned for ASSAULT BREAKER—as well as subsequent "smart weapons" concepts for standoff precision strike against mobile, elusive targets—has not been acquired or deployed. Among the reasons:

- Firing a weapon without directly viewing and positively identifying the target is not permitted under current rules of engagement. It represents a new way of thinking.
- Constantly improving technology makes it difficult to settle on a system solution that seems "smart enough" and provides users with evaluation tools that can test advanced munitions over their full functional range with statistically meaningful results.
- Smart weapons are perceived as costly, even though their cost per target killed—especially for attack for mobile, elusive targets—is expected to be lower than for other weapon types. Desert Storm proved just how difficult and expensive it was to find and attack Scud launchers using manned aircraft with conventional munitions.
- Smart weapons could reduce the need for manned platforms, which the Services and Congress tend to protect. (There are natural tradeoffs between how "smart" a munition needs to be relative to the system that delivers it to the target area.)

In the case of naval stealth and standoff precision strike, DARPA played an instigating role in the development of several disruptive surface ship concepts. Lacking a strong impetus for change and consistent high-level imprimatur, the Navy has taken these concepts no further than prototypes. Sea Shadow was canceled when the Navy perceived that continuation would require funds from its own budget. Arsenal Ship threatened the role of naval aviation in shore engagements. Shifting plans from the Arsenal Ship to DD-21 to DD(X) reflects a less disruptive approach to surface ship concepts than those conceived by DARPA.

As in the case of standoff precision strike, ISR investments have been a core area of DARPA research since its inception, yielding a broad range of component and subsystem breakthroughs: phased-array, synthetic-aperture, foliage-penetrating, and over-the-horizon radars; uncooled infrared detectors for night vision; and high-bandwidth, anti-jam data links and communications systems. DARPA has focused on developing crosscutting capabilities beyond the purview of a single Service. In particular, it sought to bring ISR capabilities to tactical users.

In the case of UAVs, DARPA recognized the warfighting potential of deploying sensing devices on small UAVs and fostered development of various systems and enabling technologies. But DARPA faced major challenges in bringing disruptive UAV capabilities to fruition. UAVs have often been caught in a death spiral, in which unrealistic Service-imposed performance requirements led to increasing complexity, which led to high costs and development difficulties, which reinforced the idea that UAVs could not affordably meet requirements. To bring an operational tactical UAV into the field, OSD leaders and Combatant Commanders, with considerable support from DARPA, invented mechanisms such as Advanced Concept Technology Demonstrations to get UAVs into operators' hands, circumventing Service development and acquisition systems. Predator and Global Hawk are examples of this, having been successfully employed in combat despite being only experimental systems. It must be emphasized, however, that they resulted from a case-specific initiative more than a decade after initial proof of concept, not from a systematic process designed to move transformational capabilities into service.

In a similar vein, Discoverer II's high cost and the failure of OSD and Service leadership to address perceived mission overlaps between organizations led to imposition of formal acquisition requirements, which it could not meet in its immature state. Despite continuing research focus on the types of capabilities Discoverer II was intended to demonstrate, it is unclear how the disruptive elements of Discoverer II will be developed and demonstrated.

B. Management Lessons

As the preceding cases have highlighted, development and deployment of a disruptive capability involves the cooperation and commitment of a large number of people in different organizations working from various perspectives toward a common goal. With so much activity in so many quarters, and with such a mixed record of success, it is difficult to glean general management rules. However, one thing is clear: achieving transformation via implementation of disruptive capabilities requires both vision and leadership:

- VISION: Nothing happens without motivated, results-driven individuals who are willing to challenge accepted approaches and persevere, sometimes even going around their own organizations and established bureaucratic processes to promote a concept. This is the area in which DARPA has often played a lead role.
- LEADERSHIP: Acquisition and deployment of disruptive concepts requires high-level support if they are to be taken seriously by the Services and survive the budget and requirements processes. It is here that high-level players in the Office of the Secretary of Defense—the Director of Defense Research and Engineering, the Under Secretary of Defense for Acquisition, Technology and Logistics, and the Secretary of Defense—have typically played the lead role.

We analyze each of these elements in turn, drawing lessons from the detailed reviews.

1. Vision

DARPA's primary role is developing visions of transformational capabilities—creative combinations of technological opportunities and operational adaptations—and proving them out to the point that OSD leadership is prepared to push them forward. *Perhaps the most important effect of DARPA's work is to change people's minds as to what is possible*. The programs reviewed in this report point to the following crosscutting themes and institutional processes that, if refined and practiced, can maximize DARPA's impact on DoD and help foster future RMAs.

Investing in Basic Technologies that Can Create Fundamental Technical Advantages

Part of DARPA's success stems from steady, forward-looking investment in an array of generic technologies. RMAs are often based on technologies whose national security significance is unclear at the outset and whose funding would be nearly impossible to justify in accounting terms. DARPA's ability to undertake projects that are not tied to validated military requirements distinguishes it from Service labs. Most of these efforts will not yield immediate, tangible results. But through sustained investment, the initial science can be built into progressively more integrated systems and revolutionary capabilities. In the case of standoff precision strike, DARPA investments in advanced radar concepts, information fusion, seekers, microelectronics, and various types of detectors provided the underlying technologies from which a disruptive military capability could be formed.

Early DARPA funding has also supported US dominance of entirely new industries—microelectronics, advanced computing, networking, and other information technologies—that underlie many of the military systems capabilities associated with the RMA. The case of IT development is perhaps one of the best examples of DARPA betting on good people developing generic, cross-disciplinary technologies. Back in 1962, J.C.R. Licklider, the new Director of DARPA's Command and Control Research,

> (set) in motion the forces that would give rise to essentially all of modern computing: time-sharing, personal computing, the mouse, graphical user interfaces, the explosion of creativity at Xerox PARC, the Internet—all of it. Of course, not even he could have imagined such an outcome, not in 1962. But it would have delighted him no end. After all, it was why he had uprooted his family from the home they loved, and why he had come to Washington to work in the sort of bureaucracy he hated: because he believed in his dream. Because he was determined to see it become real. Because the Pentagon—though some of the higher-ups didn't quite seem to understand this yet—was putting up the money to make it real.[164]

Building Research Communities

Beyond technology investments, DARPA often acts as a leader and catalyst for cross-fertilization among forward-thinking academic researchers, military operational experts, and private industry. Building such relationships encourages the conception and development of disruptive capabilities by facilitating the exploration of novel ways to apply technology to military problems. Once a concept is proven, the Services may be more willing to support the next phase of development. Melding these perspectives can also promote mastery of their eventual production and application.

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[164] M. Mitchell Waldrop, *The Dream Machine: J.C.R. Licklider and the Revolution that Made Computing Personal* (New York: Viking Penguin, 2001), p. 6.

Conceiving novel, cross-disciplinary programs depends in large measure on good people with good instincts about what could be valuable. DARPA PMs are often mid-level people, from government, industry, and academia, who are experienced enough to have a track record but are young enough to be open minded and able to work in an environment of real uncertainty; i.e., no specifications. People who are driven to achieve technical success should be sought, rather than those focused on career success, as they are less afraid to fail. Military users, who operate in a requirements-driven environment, are typically not visionaries.

Defining Strategic Challenges in Detail Across Multiple Scenarios

New technologies become disruptive capabilities when married to implementing concepts that employ them for strategic advantage. This suggests that DARPA should, as it did in years past, support independent evaluation of concepts of operations for new technologies. For instance, the study efforts undertaken by DARPA Director Steven Lukasik set the stage for much of the standoff precision strike work that followed. What is critical is to define and articulate in detail fundamental, strategic challenges that face US forces in multiple potential battle scenarios. Well-articulated challenges and guidance—what is important, not how to achieve it—is required to set specific, credible research priorities, communicate persuasively with program managers, overseers, and contractors, and develop a "critical mass" of research effort.

Developing Disruptive Systems Concepts

Based on detailed understanding of strategic challenges, DARPA systems programs experimented with creative approaches—typically beyond the purview of a single Service—to address fundamental national security problems. (The Services are unlikely to nominate new missions that they cannot individually accomplish, due in part to competition among the Services.) The program areas reviewed illustrate the important role DARPA has played in breaking paradigms by demonstrating novel linkages between technical capabilities and defense missions.

Testing Promising Disruptive Concepts in Large-Scale, Integrated Demonstrations

At the urging of entrepreneurial DARPA PMs who were willing to act before having all the answers (and hence risk failure), DARPA has been willing to commit significant resources to refinement of capabilities through prototyping and demonstration. DARPA's willingness to support the development and demonstration of integrating, truly "joint" demonstrations helped convince DoD leadership, Congress, and the Services of the potential value of new approaches.

A fundamental tension for DARPA is balancing its pursuit of high-risk research independent of a defined need with its need to demonstrate capabilities that address a specific strategic problem (but not defined requirements). Although integration projects may be just as "high risk" as research projects, philosophically, culturally, and managerially, these are very different processes. Research is visionary, while development is pragmatic. Researchers have a different mindset than system builders. Long-term research is an open, wide-ranging, relatively slow process aimed at exploring the unknown to discover new ways to solve problems. Prototyping and demonstration are processes of closure that involve refining the known, making tradeoffs and implementing imperfect solutions *now*. Commercial industry faces the same problem: when to sow and when to reap.

The DARPA Director needs to mediate between these missions and, more importantly, bridge the two communities. One way the apparent tension between DARPA's research and systems integration projects can be resolved is by considering total risk. A small-scale research project and a large systems integration may have the same overall risk. The research project's risk will be based on fundamental scientific uncertainties. The integration project will be based on the probabilistic sum of the technical risks associated with each component, as well as the risks associated with integration engineering. Hence, the individual components of a systems integration project may not have high risk, but the overall project may still meet DARPA's high-risk criterion. DARPA management could apply a uniform total risk criterion to all projects, regardless of whether they are scientific studies or systems integrations.

In terms of bridging communities, DARPA was effective in the cases covered here in part because a strong axis between DARPA and top OSD leadership formed around ambitious outcomes, not technologies per se. This outcome orientation was key to building support across organizations for maintaining the focus and support of top DoD leadership, particularly in undertaking and following through on large-scale demonstrations. An outcome orientation is also important in explaining DARPA programs to Congress.

Finally, in considering appropriate metrics for DARPA, it is important to note that DARPA does not control the Services' implementation of new capabilities. Hence, its success should not be measured solely by the fielding of technologies it helped develop.

We will address this issue more fully in the next section. It is also important to note that the success of a disruptive change may not be readily apparent. The Soviets reacted to the emerging US Air-Land Battle capability demonstrated by ASSAULT BREAKER even though the exact capability was never deployed.[165]

2. Leadership

The case studies make this clear: *If fielded disruptive capabilities are the objective, it is insufficient for DARPA to create an example and then rely upon the traditional Service acquisition system to recognize its worth and implement it.* In other words, demonstrations alone are not enough. Because acquisition and deployment of disruptive capabilities challenge existing programs and bureaucracies, it is difficult to find eager customers for them. Also, because new capabilities are not technically mature or operationally robust, the Services will generally be reluctant to take on the significant and potentially costly risk reduction efforts required to move them into acquisition. Hence, DARPA programs aimed at disruptive capabilities generally will not transition quickly or in a smooth, straightforward way.

Taking a disruptive capability from DARPA demonstration into acquisition and deployment requires an integrated, consistent management and leadership effort at levels in DoD higher up in the organization than DARPA: the Director of Defense Research and Engineering and the Under Secretary of Defense for Acquisition, Technology, and Logistics. These senior OSD leaders must firmly believe that disruptive capabilities are critical to US military transformation, and they must have allies among top Service leadership in order to alter the course of ordinary organizational politics. That often means exercising their authority to overcome various forms of resistance: (1) of people to new ideas; (2) of existing programs to perceived competition; and (3) of requirements and acquisition organizations to uncertainty and risk. DARPA's progressive organizational demotion over the years (from directly reporting to the Secretary of Defense to reporting to the Director of Defense Research and Engineering, two levels below the Secretary) has put a premium on DARPA developing close working relationships within OSD.

DARPA's success depends not only on strong support from OSD, but also on clear guidance from it on strategic needs. During periods when DARPA is not supported and given strong external guidance, it is more vulnerable to pressure from Congress and

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[165] William E. Odom, *The Collapse of the Soviet Military* (New Haven, CT: Yale Univesity Press, 1998), p. 76.

the Services to demonstrate that its programs have near-term military relevance. This is partly because, during such periods, DARPA tends to focus on technology development rather than systems applications. They are then more susceptible to pressure from the Services to undertake projects that directly support existing Service initiatives. Arsenal ship, Unmanned Combat Aerial Vehicles, and Future Combat Systems are recent examples. When DARPA undertakes research programs in partnership with a Service, it must be careful to maintain openness to unconventional approaches and follow through with significant, outcome-oriented results as opposed to short-term deliverables.

Specifically, successful transition of disruptive capabilities requires that OSD leadership provide DARPA with the following kinds of support.

Brokering Deals with Service Leadership

The first hurdle in implementing a disruptive capability is finding a way to engage a Service or Services. Often, a problem arises when DARPA has progressed to the point of seeking a large-scale demonstration. Earlier research is too abstract and distant to threaten a Service's organizational "turf," but the engineering required to build and test a prototype is similar to the work traditionally done by Service program offices. Services then resist the new approach in part because their PMs are trained—appropriately—to do everything possible to make their own programs succeed. DARPA programs that appear to overlap or obviate Service programs are naturally viewed as threatening.

Part of DARPA's strength is that it does not develop systems for itself, and thus has no existing systems base to protect. Hence, as long as DARPA and OSD leadership strongly believe in a concept, DARPA PMs should be encouraged to act alone in the face of Service criticism to create compelling demonstrations But as the time approaches for the new capability to transition to acquisition, Service support must be obtained.

DARPA's successful transitions of stealth, standoff precision strike, and ISR show that the ability of OSD leadership to secure Service support depends on "firm handshakes and strong arms." "Firm handshakes" represent time and effort invested in building good working relationships with Service stakeholders. During the 1970s, DDR&Es made a point of getting to know the Service R&D chiefs personally and involving them in broader OSD policy decisions. Hence, they were able to obtain advocacy from key Service players when the time came to push for an otherwise unpopular concept. "Strong arms" represent exercising authority to overcome the resistance from Service PMs and bureaucracy wedded to current approaches and to redirect resources required for transition. Independent advisory bodies can play a role in building consensus for new ideas and approaches, but direct, unflinching exercise of authority is considerably more effective. In some instances (e.g., Stealth), OSD leadership has softened the financial impact of a disruptive capability on a Service by defraying the costs, thus buffering the near-term effect on existing Service priorities.

Lack of sustained top leadership support was one of the key barriers to early deployment of UAVs. In the late 1970s, Under Secretary Perry believed that Service UAV programs were progressing well and did not require his intervention.[166] DARPA Director Heilmeier ended DARPA's mini-UAV program in 1978, fully expecting that the Services would move the demonstrated technology into fielded systems. Unfortunately, the Services were unable to follow through. DARPA's High Altitude Long Endurance (HALE) UAV program in the 1980s led to important new capabilities, but these received only limited deployment in highly classified intelligence applications until Perry returned as Secretary Defense.

Creating An Independent Organization within A Service Or in An Outside Agency

Once top-level Service support has been secured, it becomes necessary to find an organizational home for acquisition. This is inherently difficult from within existing organizations because disruptive concepts are generally perceived as threats to their programs. A technique that has been used successfully by OSD and Service leaders is to seek out forward-thinking officers and encourage them to build an independent organization outside the existing Service structure. This approach was used for the F-117A and UAVs (in the 1990s). In the 1950s, Admiral Hyman G. Rickover, with nuclear submarines, and General Bernard A. Schriever, with ICBMs, set up separate organizations to facilitate acquisition of those new capabilities. Indeed, this technique has been noted as a critical element of peacetime innovation in several other military organizations around the world, as the formation of a new organization creates a career path for innovative military officers.[167] By contrast, Arsenal Ship was intended for quick development by its Navy advocates, but lack of an independent constituency doomed the

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166 William Perry, Interview, November 26, 2001.

167 Steven P. Rosen in *Winning the Next War* (Ithaca, NY: Cornell University Press, 1991) argues from several cases that military innovation in peacetime "has been possible when senior military officers with traditional credentials, reacting…to a structural change in the security environment, have acted to create a new promotion pathway for junior officers practicing a new way of war." (p. 251) Interestingly, Rosen finds that, although implementation of innovative systems requires significant funding, "rather than money, talented military personnel, time and information have been the key resources for innovation." (p. 252).

program when one of its key proponents died. Creation of the Future Surface Combatants Program by Admiral Charles S. Hamilton (the PM for Arsenal Ship and current Program Executive Officer for Surface Ships) may provide the impetus required for successful acquisition of the new capabilities.

When a disruptive concept is inherently joint and thus not easily assimilated by a single Service, an alternative to setting up an independent Service organization is creation of a new agency outside all the existing Services. An example of this was the Defense Airborne Reconnaissance Office (DARO), created in the wake of lessons-learned from the Gulf War and a growing interest by the Combatant Commands in improved ISR and UAVs. Though short-lived, DARO succeeded in focusing sufficient leadership attention and momentum to move "third generation" ISR and UAV capabilities into acquisition and application.

The history covered here suggests that Service-independent organizations may be a more effective way to implement disruptive capabilities than joint program offices because they avoid the need to reconcile competing Service priorities. This is even truer now that joint program offices are controlled by a single lead Service. For example, when OSD created joint program offices to implement ASSAULT BREAKER, individual military capabilities were implemented piecemeal—not as the integrated, intrinsically joint operational system envisioned. The Discoverer II joint program office approach failed because of the competing needs of the Air Force and NRO.

Working with Congress to Protect Funding

Once an agreement has been made to create an independent organization, it must then be funded and protected during budget battles. OSD and Service leadership must work with Congress to prevent the organization's funding from being pirated to resolve budget competitions among traditional programs. A strongly coordinated approach is mandatory to overcome the effects of lobbying by competing contractors and voices of disenchantment from the Services. (Programs are easier to shield when they are classified, as with the F-117A.) For instance, Discoverer II was clearly undermined by lack of unified support. Although some senior-level leaders supported it, they were not able to distinguish it as a uniquely needed capability. The Secretary of Defense wrote to congressional appropriators in support of the program in a letter that addressed disparate programs and considerations. The Service partners also made arguments in support of DII, but only as a small part of a much more extensive capability. Furthermore, although the transition path for Discoverer II appeared clear given that the Air Force was a partner, Congress was frustrated by the fact that the Air Force struggled to find funds to demonstrate it. The Air Force attempted to use S&T dollars instead of the engineering manufacturing development resources originally budgeted. Congressional observers legitimately questioned the funding stability of the program, given these difficulties, and consequently terminated the program.

Disruptive capabilities will also face an uphill battle in Congress if they must compete with large platform acquisitions. One reason is jobs. For example, UAVs require few people to build them and cost only a few billion dollars to deploy, whereas production of fighter aircraft keeps thousands of people employed and infuses hundreds of billions of dollars into congressional districts. DARPA's standoff precision strike concepts of the 1980s also competed for the missions of existing large platforms, such as the M1 tank and manned strike aircraft.

Providing a Clear, Top-Level Imprimatur for Risk Reduction and Acquisition of Specific Capabilities

Top DoD leadership support is instrumental in addressing the technical and bureaucratic acquisition issues involved in bringing immature technology and systems to fruition. DARPA prototype systems generally are not suitable for user experimentation. Hardware designs are not optimized and are not environmentally rugged. The prototypes will neither fully solve the intended military problem nor meet all operational needs, much less the more stringent criteria of formal DoD testing and evaluation organizations. Finally, they will not have been engineered for cost. By virtue of their mission and organizational incentives, the Services focus on pragmatic operational issues and hence are generally reluctant to adopt a system for which these types of technical risk reduction activities have not been mostly completed. This is particularly true for disruptive capabilities to which the Services may be resistant in the first place, and for large-scale, relatively expensive systems that represent competition for funding.

Top leadership can help address technical acquisition issues by employing an "incubator model," in which a new capability is initially focused on a highly specific and limited application area and only later, as developers and users ascend the learning curve, maturing the approach to address more complex missions. Historically, mechanisms to accomplish risk reduction have been ad hoc. Elaborating on their work with the 1986 President's Blue Ribbon Commission on Defense Management, William Perry and David Packard sent a letter (dated April 3, 1989) to Secretary of Defense Richard Cheney recommending a two-phase prototyping process (Figure 7). The first phase would involve building a technology-driven prototype for experimental demonstration of a capability, akin to the type of demonstrations DARPA has frequently undertaken. The second phase would build a risk reduction prototype aimed at meeting specific military requirements at acceptable cost. Once an adequate risk reduction prototype has been built, DoD experimentation programs and initiatives designed to encourage transition of disruptive concepts may be applied. DoD has encouraged experimenting with new operational concepts through the Advanced Concept Technology Demonstration (ACTD) Program, created in the 1990s. New Battle Laboratories have been created, and the US Joint Forces Command has taken an increasing role in experimentation with new technologies and operations concepts.

Figure 7. Risk Reduction Prototyping—A Link between DARPA Development and Service Experimentation and Acquisition

Top-level support—typically in the form of direct intervention and exercise of authority—is critical to support working-level managers in quickly overcoming bureaucratic barriers during development and experimentation. It may also be helpful for top-level champions to set clear, but feasible development timelines so that programs can be brought to an acquisition decision before resistance gathers and while most of the people who brokered the key deals are still in power. Once risk reduction prototypes have been developed and tested, DoD leadership may again be required to move the resulting capability into a Service or joint acquisition organization in order to overcome challenges from the proponents of existing systems who perceive the disruptive capability as a threat.[168] In the case studies described in this report, successful acquisition typically involved the personal attention of top DoD leadership. Recent acquisition process reforms and the current emphasis on "spiral development" have attempted to address some of the systematic barriers to acquisition of disruptive capabilities, but there are no formal mechanisms in place to address the problem. The problem is particularly acute for joint programs.

The development of the F-117A is an example of how OSD and Service leadership applied an incubator model and overcame bureaucratic barriers to acquisition. The executive committee managing its development kept the program focused on a specific mission that existing aircraft could not safely perform: attack of heavily defended fixed targets. They articulated and enforced a clear imprimatur to get the system built and operating quickly, with Under Secretary Perry personally intervening when necessary to address bureaucratic issues. The fact that the program was performed in extreme secrecy allowed a relatively small group of top managers to resolve problems and make technical and operational tradeoffs quickly, without disruption. Secrecy also protected the independent Air Force combat wing, allowing it to develop operational concepts without interference.

By contrast, the UAV development process illustrates the type of self-reinforcing death spiral of technological difficulties and changing Service demands that evolves when Service organizations burden a maturing concept with too many missions. Lacking leadership to keep the development focused, various organizations in the Services demanded increasing capabilities and consequently increased the technological challenges of subsystem integration and weight. These problems led to cost overruns, failed tests, and limited capabilities.[169] Subsequent budget cuts and program cancellations made

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[168] This problem is not unique to DoD. Potentially disruptive new products also fail in the commercial world because they threaten established, profitable product lines. At an early stage of development, it is often unclear whether the new product will be received favorably by customers, many of whom may be new customers. (Like DoD, business must often "create customers" for innovative new products.) The high start-up costs associated with launching a new product mean that it will generally be a near-term drain on company profits. For disruptive products, achieving profitability may take even longer. If they are forced to compete against near-term profit or asset utilization criteria set by incumbent business areas, they may die before ever being able to demonstrate their market potential. In enlightened companies, various mechanisms are employed to foster and shield innovative developments from pressure exerted by their established product lines. Innovations that are not exploited by the developing firm often migrate to competitors, who use them to capture market share from the originators.

[169] See, for example, US General Accounting Office, *Unmanned Aerial Vehicles: DoD's Acquisition Efforts;* and *Unmanned Aerial Vehicles: Progress of the Global Hawk Advanced Concept Technology Demonstration* (Washington, DC: US Government Printing Office) GAO/NSIAD-00-78.

UAVs an even harder sell. Recent successes in UAV transition can be traced to strong central control of their development through DARO and the use of the ACTD program for risk reduction prototype development.

C. Looking to the Future

The US security environment has changed fundamentally over the past several years, as the terrorist threat has intensified. DARPA's primary role as creator of advanced defense technology remains, while the emphasis is changing to address the new threat. One lesson from earlier DARPA successes is that careful threat characterization can suggest technological approaches that may be usefully employed as counters. DARPA worked with OSD and the Services to achieve and draw upon this understanding, which in turn helped shape and focus its technical approaches. DARPA then conceived, tested, and demonstrated new capabilities beyond those being pursued by the Services. This remains an excellent model for DARPA to follow in the current security environment.

DoD's technology environment has also fundamentally changed. DARPA played a significant role in developing microelectronics and information technologies and, in conjunction with defense contractors, shepherded their integration into disruptive "systems of systems." Those technologies, which underlie many of the revolutionary capabilities described in this report, are now mature. Their further development will be dominated by commercial firms, many outside the US, which collectively spend much more on R&D than DoD spends. Profound shrinkage and consolidation in the defense industrial base has affected the level and type of technology investment.

As with microelectronics and information technologies, DARPA must play a leading role in identifying and fostering new technologies that could provide the US tremendous national security and economic advantages in the future. Rapid growth areas such as nanometer machines, biotechnology, autonomous systems and robotics, and networked sensor arrays present myriad future opportunities. However, in the face of the new technology environment, new DARPA investment strategies are called for. To take advantage of the huge resources that commercial industry is investing in R&D, DARPA must devise appropriate ways to track emerging technologies in industry and work in partnership with the firms developing them. This should include both domestic and foreign companies that have not traditionally been suppliers to the US government.[170] In

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[170] Walter Morrow, Jr., *Report of the DSB Task Force on the Technology Capabilities of Non-DOD Providers* (June 2000).

parallel, DARPA must maintain a process that regularly reevaluates DoD needs and emerging technologies.

Without the clear, strategic imperative and OSD leadership that drove the technical and systems triumphs outlined in this report, DoD will most likely be unable to develop and implement disruptive capabilities in the future. It is doubly difficult to achieve disruptive changes when the US military is deemed to be very capable and successful. The key is DoD leadership. They must firmly believe in fostering innovative technologies and resolve to create an environment that is supportive of new ideas, true experimentation, learning, and adaptation. As emphasized in the September 2001 Quadrennial Defense Review Report, transformation is as important today to DoD as it was 30 years ago. Guided by an understanding of evolving defense needs and emerging technologies, DARPA and OSD must formulate an agenda that fuses high-level policy, technology, and operational concerns to develop disruptive capabilities that provide the US strategic competitive advantage in the future, putting the US at the forefront of future RMAs.

Appendix A
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Appendix B
GLOSSARY

ACTD	Advanced Concept Technology Demonstration
AGS	Advanced Gun System
APAM	Anti-Personnel/Anti-Materiel
ARPA	Advanced Research Projects Agency
ATACMS	Army Tactical Missile System
ATH	Automatic Terminal Homing
CIA	Central Intelligence Agency
CINC	Commanders in Chief
CNO	Chief of Naval Operations
DAB	Defense Acquisition Board
DARO	Defense Airborne Reconnaisance Office
DARPA	Defense Advanced Research Projects Agency
DDR&E	Director of Defense Research and Engineering
DII	Discoverer II
DNA	Defense Nuclear Agency
DoD	Department of Defense
DSB	Defense Science Board
DTED	Digital Terrain Elevation Data
EEMIT	Experimental Evaluation of Major Innovation Technologies
FIA	Future Imagery Architecture
FLIR	Foward Looking Infrared
GLOMR	Global Low-Orbit Message Relay
GMTI	Ground Moving Target Indication
GPS	Global Positioning System

HALE	High Altitude Long Endurance
ICBMS	Intercontinental Ballistic Missiles
ICNS	Integrated Communications/Navigation System
IOC	initial operating capability
ISR	intelligence, surveillance and reconnaissance
IT	Information Technology
ITASS	Integrated Target Acquisition and Strike System
JDAM	Joint Direct Attack Munition
JFCOM	Joint Forces Command
JPO	Joint Program Office
JROC	Joint Requirements Oversight Council
JSTARS	Joint Surveillance Target Attack Radar System
JTACMS	Joint Tactical Missile System
LSI	Leading Systems Incorporated
MCE	Mission Control Element
MFSD	Maritime Fire Support Demonstrator
MLRS	Multiple Launch Rocket System
MNS	Mission Need Statement
MTI	Moving Target Indicator
NASA	National Aeronautics and Space Agency
NATO	North Atlantic Treaty Organization
NRO	National Reconnaissance Office
NSF	National Science Foundation
OSD	Office of the Secretary of Defense
OTA	Other Transaction Authority
PM	Program Manager

R&D	Research and Development
R&E	Research and Engineering
RFP	Request for Proposal
RMA	Revolution in Military Affairs
RPV	Remotely Piloted Vehicle
SAM	Surface-to-Air Missile
SAR	Synthetic Aperture Radar
SBR	Space-Based Radar
SC-21	Surface Combatant 21
STD	System Technology Demonstrator
T-16	Patriot Missile
TAWDS	Tactical Air Weapons Direction System
TGSM	Terminally Guided Submunitions
TRADOC	Training and Doctrine Command
TTO	Tactical Technology Office
UAV	Unmanned Aerial Vehicle
USG	United States Government
WAAM	wide area anti-armor munitions

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14. ABSTRACT

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 (DoD) 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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