Fifty years of **inventing the future**

The Defense Advanced Research Projects Agency, created in February 1958, has been responsible for many of the nation's most innovative technology breakthroughs, from the first Internet to walking robots. The history of DARPA's organization and method of operation shows that the key to its many achievements has been the freedom to fail — to pursue the most futuristic concepts, unfettered and amply funded, wherever they may lead. To DARPA, the word "impossible" remains a challenge rather than an obstacle to success.

One of the most unusual government agencies in the world began life on February 7, 1958, as a direct response to two major technology leaps by the Soviet Union: nuclear testing and the launch of Sputnik.

DOD directive 5105.15 created the Advanced Research Projects Agency, or ARPA, giving it responsibility "for the direction or performance of such advanced projects in the field of research and development as the Secretary of Defense shall, from time to time, designate by individual project or by category."

In the years that followed, the agency's name kept alternating, depending on the focus of the president or Congress. A second DOD directive on March 23, 1972, added "Defense" to its name and established DARPA as a separate agency under the Office of the Secretary of Defense. Two decades later, in 1993, President Clinton dropped "Defense," as part of a strategy to promote technology as a stimulus to economic growth. Three years later, Congress put "Defense" back into the agency's name.

For simplicity's sake, we will use the name DARPA throughout.

DARPA has been at the forefront of numerous technologies across a broad range of disciplines, ranging from ARPAnet's creation, which led to the Internet, to walking robots. But among the agency's

Copyright© 2008 by the American Institute of Aeronautics and Astronautics.

1958—2008

most public contributions have been programs related to space and aviation. In many cases, DARPA's research was decades ahead of the actual implementation of new technologies—and some programs that were considered failures at the time laid the foundation for significant advances 10, 20, or 30 years later.

President Eisenhower's secretary of defense, Neil McElroy, played a prominent role in DARPA's creation. McElroy saw the new entity not as a supporter of mainstream defense R&D but as a pursuer of technology "will-of-the-wisps," and as the central source of vast weaponry for the future. The agency's vision was to be beyond current or near-future needs, to take ideas that often had no obvious connection to the Army, Navy, Air Force, or Marines at that time and to determine their feasibility and potential application to a still-unknown future battlespace.

Although DARPA's role often did include current and near-term requirements, especially in the early years, McElroy's concept remains embodied in the agency's self-described role: to be on the "Far" side of technology while the rest of the government R&D world is largely on the "Near" side.

According to *Bridging the Gap,* a DARPA work describing the agency's role, the Far side "represents fundamental discoveries, where new science, new ideas, and radical new concepts typically first surface. People working on the Far side have ideas for entirely new types of devices or new ways to put together capabilities from different services in a revolutionary manner. But the people on the Far side have a difficult, sometimes impossible, time obtaining funding from those on the larger Near side because of the Near side's focus on improvements against current, known problems.

"Whenever there have been technological surprises, the people typically surprised are on the Near side. There are always a few people on the Far side who knew that something could be done, but they could not obtain the resources to execute their ideas. The Soviets beating the U.S. into space with Sputnik in 1957 is a prime example. Sputnik motivated President Eisenhower to create DARPA in 1958 to bridge the gap between these two groups."

It thus became DARPA's mission to find and exploit Far side people and ideas, then move their results to the Near side as quickly as possible. The emphasis was on probable or possible needs of future commanders, and on creating new core capabilities for DOD. That began with space and missile defense and quickly grew to encompass aviation, with the latter often among the most visible Far side efforts.

"Aerospace has been a major part of DARPA over the past 50 years; we were born because of space, of Sputnik," DARPA's current director, Tony Tether, tells *Aerospace America.* "President Eisenhower wanted to create an agency whose sole purpose was not to be affiliated with any one service, but to look for those ideas whose time perhaps had come to be taken from fundamental science to an application that, if it could be done, would have a significant impact on the national security of the United States.

"For the first couple of years, we were almost all space. In fact, it almost died in 1960 when the space part was given to NASA and the National Reconnaissance Office [NRO], which was created out of DARPA. One of the first satellite reconnaissance programs—Corona—was started at DARPA and transitioned to the NRO.

"DARPA also was the agency that created what became Saturn 5; the agency felt it needed an enormously large booster to put things into orbit, even though at that time the conventional wisdom in the military was that no one needed to go into more than a 600-mi. orbit. We transitioned that to NASA, who finished it, but when President Kennedy said we would go to the Moon, it was comforting [that] someone was building a booster that would take us there."

At the same time, directors and managers through the decades have struggled

with the concept of rocket propulsion, which one former director says is little changed from the chemical explosive techniques the Chinese invented thousands of years ago. As a result, an agency Holy Grail has been to make major breakthroughs in rocket propulsion, thrust, and propellants—definitely a DARPA-hard problem because of the high energy density required.

DARPA has been able to continue pushing the envelope because of its unique charter, under which failure is considered a necessary part of the technology revolutions its scientists are promoting. That focus often leads to a perception that it is primarily a basic research organization. However, such research, which creates knowledge, accounts for only 5% of the agency's budget; the remainder is applied to exploiting that knowledge to create new capabilities for national security.

This approach has created a sometimes strained relationship with the military, as the agency pursues work the services are unlikely to support. In some cases they even flatly oppose such research because it does not fit their current roles or missions or, especially in aviation, because it challenges existing systems or operational concepts that the services have striven to make as efficient as possible.

While DARPA is given considerable free rein to pursue such projects, it is still subject to DOD oversight and review. It is also required, typically by its own directors, to show that a specific program will result in useful advances in military capability—even if it may not reach fruition for decades—and that the agency is not simply pursuing the program because it can.

"Everything we do has some national security vision," Tether says.

As he explained at a DARPATech conference in August 2007, DARPA is "a place for people with ideas too crazy, too far out, too risky, even considered by some as bad, that have turned out to be major game-changers for the United States. Over the past 50 years, the U.S. has established strategic and tactical dominance in many areas; if the technology was a game-changer, chances are DARPA had a role."

As a result, many of the technologies being deployed in the global war on terror, or in support of space exploration, or as part of ongoing efforts to advance the capabilities of next-generation aviation or missile defense, have arisen from research no other government agency could have pursued and few corporate R&D departments could have justified.

In some cases, the turnaround from disinterest in a technology—or outright derision of it—to perceiving it as an invaluable asset has been spectacular, albeit decades in the making. At the top of that list is the unmanned aerial vehicle.

During the last half of the 20th century, industry and military alike joked that UAVs were the mechanical vampire version of Rodney Dangerfield—they got no respect, yet kept coming back to life despite repeated stakes to the heart. The exception to that was at DARPA, where UAVs have been part of the agency's culture from its earliest days.

> *"DARPA executes its strategy by sponsoring specific revolutionary, high-payoff research and development programs [and pursues] its strategy by bridging the gap between fundamental discoveries and their military uses."*
>
> **DARPA Strategic Plan, from *Bridging the Gap***

"DARPA's greatest contribution in the aviation field is the fact we were doing UAVs when doing unmanned vehicles was not a cool thing to do," Tether says. "We basically created that technology, not that we were doing it by ourselves. In the late '60s/early '70s, we started programs that were highly classified. One eventually became Global Hawk, in the '90s. Predator started at DARPA in the late '70s/early '80s, called Teal Amber."

During DARPA's first three decades, there was rarely a period when it was not working with the services or, when military interest lagged, on in-house ways to improve UAVs. In the 1980s, that included support, with the Navy, of Boeing's Condor long-range UAV and the Army's Aquila, an outgrowth of an earlier DARPA-Army collaboration on the Praeire Mini-RPV. Although neither survived, Condor is considered the conceptual godfather of the Northrop Grumman Global Hawk, which has set UAV range and endurance records while advancing the concept of autonomous flight.

In 1988, Congress transferred all UAV RDT&E from DARPA and the individual services to a new joint program office. Shortly thereafter, the DARPA-originated Amber long-endurance UAV, which had attracted Navy interest after a successful demonstration, was terminated. As often happens with DARPA R&D, however, technologies developed for Amber ultimately were incorporated into the highly successful Gnat 750 and Predator UAVs.

DARPA was brought back into the UAV world in the 1990s, managing development of the Tier II family, which included Predator and (as Tier II+) Global Hawk. Both were fielded while still in prototype and have been used extensively in Southwest Asia and elsewhere.

Similar paths were recorded by currently deployed technologies such as stealth and precision-guided munitions and are still being followed by others, such as hypersonic aircraft.

From this point, DARPA's aerospace programs will be tracked on a decade-by-decade basis. The policy of changing directors about every four years and bringing outside researchers in as program managers for limited terms has played a significant role in the shifting focus of agency efforts. It has also been an important factor in the resurrection of long-abandoned research activities, often for applications not previously considered, or for uses a director or program manager may have foreseen but could not pursue because, as often happens, the agency's vision was too far ahead of available supporting technology.

As we examine, decade by decade, some of the technologies and capabilities DARPA pursued—some to the point of great success, some to (perhaps temporary) oblivion—we may garner some clues as to what the future holds.

1958-1969

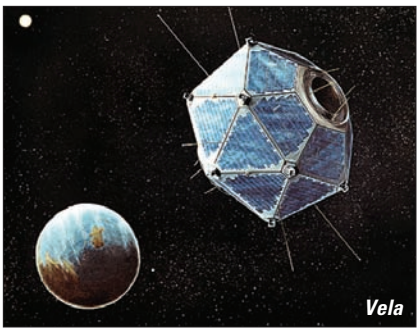
The creation of any major new government organization always means a period of working out goals and means, creating structure, even finding physical space in which to work. During its formation, DARPA had the added pressure of being called on to win back technological dominance from the Soviet Union, which had spent the years since WW II matching—and even surpassing—the U.S. in developing rockets and atomic bombs and in putting the first satellite into orbit.

SPACE

DARPA's birth a few months after Sputnik put space high on the list of aerospace pursuits for the agency's first decade. Within two years, however, with the creation of NASA, NRO, and space operations in the Army and Air Force, much of that initial space focus was gone.

It was one of the fastest transfers of programs and responsibilities in U.S. history. For example, in March 1958, DARPA was ordered to prepare and launch four Juno rockets, with payloads ranging from 15 to 100 lb, between August 1958 and January 1959, in cooperation with the Army Ballistic Missile Agency. Four amendments through July made modifications to the missions—and quadrupled funding for "salaries and expenses." But in October 1958, before the first satellite was launched under the amended schedule, the entire effort was transferred to the newly created NASA.

DARPA lost the "space race" effort to NASA, the early warning systems to the Air Force, and the intelligence satellites to NRO. But the need to detect Soviet nuclear tests from space accurately and reliably gave DARPA a continued space role for decades, along with efforts on the defense against ballistic missiles.


Vela

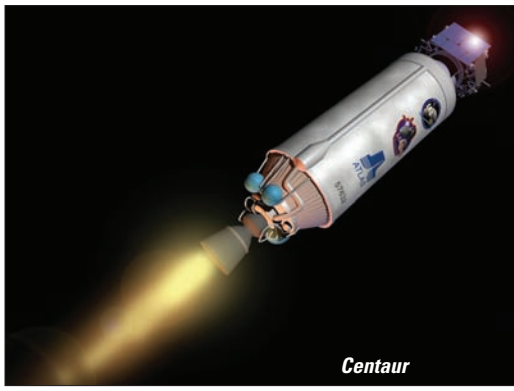
From about 1959 through 1996, DARPA did the initial research, development, and implementation of technologies—largely space-based—to detect nuclear tests both in the atmosphere and underground, and to pinpoint their locations under water. According to DARPA program officials, those efforts resolved all the issues and met all the requirements of test detection, including those still under way today.

TIROS

One such activity was DARPA's Vela satellite program, which was divided into three elements: Vela-S, to monitor nuclear explosions or radiation in space; Vela-H, dealing with high-altitude atmospheric tests; and Vela-U, to help detect underground tests.

DARPA designed the series of stand-alone satellites and their sensors, and the Air Force handled day-to-day operations. Satellites launched in the 1960s monitored space and atmospheric tests with sensors, looking for electromagnetic pulses and the characteristic optical signals produced by nuclear explosions. In later years, upgraded versions of those same sensors would be used on other satellites and applied to missile launch detection.

The importance of space to DARPA's early years can be tracked through its funding. For much of the 1960s, Vela and the Defender anti-ICBM program accounted for 60-70% of DARPA's budget, according to official agency reports. In then-year dollars, that ranged from a high of $485 million in 1959 to about $280 million for 1962-1965, after NASA and the Air Force took over much of the space program. It then dropped to $200 million by 1969, after missile defense went to the Army and the success of Vela reduced R&D requirements there.


Centaur

DARPA's funding overall has been closely linked to defense budgets—from the beginning, it has averaged less than 1% of the DOD figure. Space-related spending also has followed a peaks-and-valleys course as new efforts have been funded, only to be transferred to NASA or the services or dropped altogether in the decades that followed. In constant dollars, of course, especially with the high inflation rates of the 1970s, the fluctuations in both DARPA's total budget and what it spends on space-based programs have been even more dramatic.

During the 1960s, in addition to space-based missile defense and nuclear test detection, DARPA space included the Transit satellite, precursor to GPS and foundation of the Navy Navigation Satellite System, developed with the Naval Research Lab. It also included enhancements to Centaur and Saturn engines.

AVIATION

Over the years DARPA has made a number of contributions to various aviation components, from materials to engines to avionics. But it is best known for its X-planes. Of more than 50 aircraft given the X-plane designation in the past 60 years, more than half were sponsored by DARPA.

X-26B

The goal of an X-plane is to take high-risk, high-payoff technologies that can be tested only in flight and transform theory into reality. X-planes are not intended to be prototypes of actual future aircraft, but rather flying testbeds that will enable important breakthroughs in aviation design.

Even so, some of these aircraft did see service in the early years. One of them,

built by Lockheed and flown operationally in Vietnam, was the X-26B, a low acoustic signature spyplane, based on a Schweizer SGS 2-32 sailplane.

ROCKETS AND MISSILES

A major subset of DARPA R&D from the beginning has been development of new rockets and missiles and their components, or ways to defend against them. As outlined by Eisenhower, DARPA was intended to prevent surprise from technologies that might be being built elsewhere.

Sprint

One of its first major efforts in that respect was ballistic missile defense (BMD), which required keeping a close eye on what others were doing and developing whatever countermeasures technology allowed. BMD is perhaps the most enduring of all DARPA programs, a nonstop 50-year path seeking technologies for coping with and destroying ballistic missiles.

That included not just early work on the Sprint antiballistic missile, but also efforts on the flip side of U.S. missile development. These ranged from payload-bearing rockets to more self-contained systems such as the initial engines for Tomahawk, the nation's first cruise missile.

1970-1979

In its second full decade, DARPA went through significant changes, both in the way it viewed its role within DOD and in the way others viewed it. By 1975, incoming director George H. Heilmeier became concerned that several major thrust programs being handed to the still-evolving agency could overwhelm its ability to play the additional role of serving as the government's center for high-risk, cutting-edge research. To prevent that, he isolated the big programs, such as X-planes, into a new designation—Experimental Evaluation of Major Innovative Technologies (EEMIT).

While DARPA already had developed a solid reputation for pushing technology into new areas, it was in the 1970s that it also began to blur the line between science fiction and what would become fundamental technologies. It was the agency's enthusiasm for such R&D—and its many successes—that defined what came to be known as "DARPA-hard" problems.

Heilmeier also began his tenure by telling then-Secretary of Defense James Schlesinger that he wanted to focus on six "silver bullet" efforts, exploring capabilities to do things that could not be done before. He defined that as achieving 10 times the performance for the same cost, or equivalent capability for far lower cost.

SPACE

During the 1970s, the focus of DARPA's space activities shifted.

"We were still in space, but more on the technology component level as opposed to building large spacecraft," Tether recalls. "We were involved in developing the charged coupled device and the photonic materials that led to real-time systems in space."

AVIATION

One of Heilmeier's DARPA-hard EEMIT silver bullets involved designing an "invisible" airplane.

Invisible, in this case, meant an aircraft that could not be detected easily by radar—what later became known as a low-observable or stealthy platform. This was a major concern in the 1970s, because Soviet-developed surface-to-air missiles in Vietnam were shooting down U.S. aircraft whose jammers often were not an effective countermeasure. Israel also lost a number of aircraft to those same systems during the 1973 Yom Kippur war.

The first attempt, designated Have Blue, was built by Lockheed as a proof-of-concept stealth demonstrator. Its first flight in 1977 started the effort that led to the F-117 Nighthawk stealth fighter, which made its maiden flight just two years later.

Technologies investigated by DARPA

Have Blue

F-117

under Have Blue—and later incorporated into the F-117—included using a multifaceted surface, radar-absorbent materials, infrared shielding, heat dissipation, low-probability-of-intercept radar, active signature cancellation, shielded inlets and exhausts (along with exhaust cooling), and special coatings on the windshield.

But it was those stealth technologies, not the actual building of an aircraft, that formed the centerpiece of DARPA's program. In fact, the agency pursued an unyielding course of not inventing anything new where it could instead borrow and adapt from existing aircraft, as they did for Have Blue's flight control system, which came from the F-16. The goal was to get a low radar cross-section plane into the air in two years, for which DARPA was willing to sacrifice aerodynamic performance.

In the minds of program managers, meeting all of the Air Force requirements for a high-performance aircraft was not

DASH

nearly so important as proving the possibility of stealth as a new parameter applied to survivability and enhanced mission capability.

Heilmeier's successor, Robert Fossum (1977-1981), says this approach was not always an easy sell to contractors DARPA called on to turn their ideas into reality. For an aircraft, the usual approach—involving engine, structure, and safety engineers—complicated the agency's singular goal of creating a low-cross-section airplane.

Fossum ordered his contractor to ignore everything not directly related to the radar cross-section he specified. The result was a relatively inefficient, aerodynamically unsophisticated aircraft that had entailed a lot of compromises. But it also furthered a new technology and, he believed, again demonstrated that focusing on one goal, rather than trying to do too many things, was key to successfully developing advanced technologies, DARPA-style.

During the Vietnam war, DARPA also worked to improve UAVs (then known as remotely piloted vehicles, or RPVs) that were used for low-altitude tactical reconnaissance over enemy territory. Agency programs or enhancements to existing vehicles included the Navy's drone antisubmarine helicopter, or DASH, and a Marine Corps version called Snoopy.

While useful, those early robotic vehicles lacked autonomy and required additional effort by DARPA to deal with reliability, communications, control, sensors, and operations problems. This effort took the form of the Mini-RPV program initiated in 1971. By 1977, Heilmeier turned the Mini-RPV results over to DOD for acquisition and deployment, the traditional end for a successful DARPA program.

On the manned side, in 1976 DARPA and NASA collaborated on an effort to use forward-swept wings to improve the maneuverability of fighter aircraft. Previous attempts had fallen victim to problems in areas such as wing stability, but three years of DARPA research demonstrated that a new approach to lightweight composites could overcome that.

As the decade closed, this research was moved to a new program at the Air Force Flight Dynamics Laboratory, with the intent of developing an experimental aircraft—the X-29.

ROCKETS AND MISSILES

In pursuing its goals, DARPA developed a process of nesting multiple programs under a single larger program, combining them to address a specific need. The first of these, Assault Breaker, would be the springboard for numerous future developments. It was based on DARPA's Integrated Target Acquisition and Strike System (ITASS), a concept that involved using long-range missiles, guided by airborne reconnaissance, to attack enemy armor deep in its own territory with terminally guided submunitions.

One of the successful outgrowths of that effort was JTACMS, or Joint Tactical Missile System, which later became the Army Tactical Missile System, or ATACMS.

Assault Breaker also can be seen as an early example of what is now a core concept in the transformation efforts of the 21st-century military: a system of systems. It was neither the first nor the last example

ATACMS

FAssault Breaker

of DARPA's pursuit of new technologies that would also result in new concepts of management or implementation.

The early 1970s also saw development of DARPA's Light-Weight Radar Missile program, conducted with the Air Force to exploit solid-state radar technologies developed by the services. When DARPA concluded that the technology was too large for the preferred template—the AIM-9 Sidewinder air-to-air missile—the Air Force agreed to proceed with a larger mis-

AMRAAM

sile that met the size and weight constraints of AIM-7 Sparrow launch stations. The result was the Advanced Medium Range Air-to-Air Missile, or AMRAAM, which entered its conceptual phase in 1979 and eventually became a lighter, faster replacement for the Sparrow.

DARPA entered a new phase of missile defense research in the mid-1970s with programs that looked at applying high-power lasers to antiballistic missile efforts. Those included the Navy/DARPA Chemical Laser and the Special Laser Technology Development Program. Among the advanced outgrowths of those efforts were the Mid-Infrared Advanced Chemical Laser and the Chemical Oxygen-Iodine Laser, which became central to the Air Force Airborne Laser program.

1980-1989

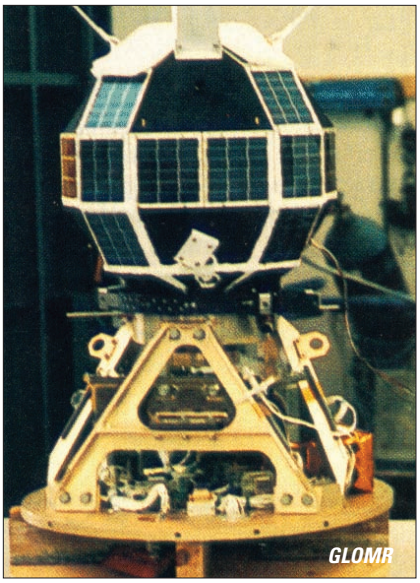
SPACE

Says Tether, "We didn't get back into space in a big way until the early '80s, when we got into building satellite warning systems. They could not only detect missiles, but also track airplanes and give the country both a missile warning system and a bomber warning system."

"In the mid-'80s we started to get out of space again, but before doing so tried to show satellites did not have to be large to have utility. We flew what was then called CheapSat, trying to do something useful for less than $1 million. And that started all the small satellite activity you now hear about."

The first of these small, lightweight "LightSats," developed by DARPA's Advanced Satellite Technology Program, was the Global Low Orbit Message Relay communications satellite, launched from the space shuttle in October 1985. GLOMR was a proof-of-concept demonstration on the use of small, quick-to-launch satellites to acquire, store, and forward data from remote ground-based sensors.

A somewhat different satellite-related effort by then-director Bob Cooper (1981-1985) involved GPS. At that time the program was embroiled in conflicts between the Air Force and Navy, each of which wanted to build its own system with different configurations. Cooper proposed a joint program with DARPA and all three services, with the Navy and the Air Force as co-deputies, but the Air Force making the final decisions.


GLOMR

Bringing that unity to GPS, while not a typical DARPA effort, put the program back on the fast track and led to today's military and civilian dependence on GPS for precision location and navigation.

As often happens under DARPA's management structure, which has short-term directors and managers, support for different elements of the LightSat concept varied.

Former director Ray Colladay (1988-1989) acknowledges being intrigued by the concept of a constellation of small, inexpensive satellites working together to provide the capabilities of a single, multi-billion-dollar multifunction platform. However, he was far less enthusiastic about the small rocket launchers, believing it would cost far less to launch multiple LightSats on a single large booster than to provide each with its own expendable launcher.

That view has often typified DARPA's road to technology development. Over the decades, each new director came in with new program managers, and each brought his or her own assessment of what was practical and what was possible, even given DARPA's usual view that "impossible" merely made the challenge more interesting.

As part of its new Directed Energy Office, created to exploit new and evolving particle beam and laser technologies, DARPA returned briefly to its roots in 1980 with Talon Gold, an ultraprecise laser pointing and tracking technology. It was part of a triad of components for space-based laser defense against ballistic missiles and aircraft. Three years later, those programs—and their personnel—were transferred to the new Strategic Defense Initiative Office (now the MDA).

DARPA also played a role in the Hubble Space Telescope, first with the design and fabrication of two lightweight graphite-fiber/aluminum matrix composite antenna booms and second through algorithms developed under its Directed Energy Program and the concept of a deformable mirror for wave front correction to provide the Hubble's superior images.

AVIATION

In his last year with the agency, Fossum pushed the UAV concept even further with Teal Rain, DARPA's original concept for a high-altitude, long-endurance, extended-range platform to perform intelligence, surveillance, and reconnaissance and target acquisition missions lasting for days or even weeks. To that end, the program looked at a variety of power systems, including nuclear, solar, and microwave, as well as exotic materials and designs.

Even as Teal Rain was failing to win enough support to move from DARPA R&D to service acquisition, the agency brought what it had learned into a cooperative effort with Boeing on that company's Condor long-range UAV, supporting flight tests of a military configuration. The all-composite honeycomb structure, autonomous controls, high-altitude aerodynamics, fuel-efficient propulsion system, and 200-ft wingspan made Condor a breakthrough in UAV development.

Equally important to potential users, during flight tests from 1986 to 1988 it demonstrated the ability to carry up to 1,800 lb of instrument payload, reach then-record altitudes of 67,000 ft, fly up to 9,000 mi., and stay aloft 2.5 days. When billed as a "CheapSat," even its $20-million price tag compared favorably to many applications otherwise requiring expensive satellites and launch vehicles. Although it met Navy requirements, the program died when its mission was transferred to the Air Force, which did not opt to acquire the UAV. Even so, Condor is now viewed as the conceptual prototype for Global Hawk.

DARPA was involved in a wide variety of aviation programs in the 1980s, some

Condor

Rotor Systems Research Aircraft

Tacit Blue

B-2

far more successful than others. But in typical DARPA fashion, even those that other agencies might have abandoned as failures added knowledge the agency would draw on (and might yet) for future, even unrelated, programs.

"It is the freedom to fail that gives [DARPA program managers] the boldness to go for the big payoffs. And fail we do!" Tether said at DARPATech. "But that's O.K.—failure sometimes happens when you're bringing new capabilities into reality; you only really fail if you don't learn what happened and stop trying to succeed. You have to try again—and again—and again."

One example is a DARPA-NASA program that built on the remnants of an earlier NASA-Army effort. Known in both iterations as the Rotor Systems Research Aircraft, the Sikorsky-built hybrid for the DARPA version was modified with an X-wing. While also intended to combine the vertical lift of a helicopter with the high cruise speed of a fixed-wing aircraft, unlike the Marine Corps AV-8B Harrier jumpjet, with rotating jet engines, or V-22 Osprey tilt-rotor, the X-wing featured a four-blade rotor mounted above two conventional turbojets. Although taxi and initial fixed-wing flight tests were conducted at NASA Dryden, the program was terminated in 1988, before it could be flown with the rotors attached.

Although some considered it a major failure because of the money spent, others, including Colladay, believed a lot of technology information was gained—such as experience with difficult control environments—even if the technologies required to achieve its goals were too far into the future at the time.

Just as Have Blue led to the F-117, DARPA's next stealth aircraft—Tacit Blue, also known by its design team at Northrop as the Whale, because of its boxy profile—laid the foundation for the B-2 stealth bomber. Unlike Have Blue and the F-117, however, Tacit Blue demonstrated the use of curved surfaces to create a low radar cross section.

While only one Tacit Blue aircraft was built, its 135 test flights in the early 1980s significantly advanced the development of low observable and radar technologies, making it one of the Air Force's most successful flying testbeds.

"Stealth is another DARPA creation, because we had some people who believed they could design and fly an airplane using Maxwell's equations and not Navier-Stokes, which basically would minimize reflection back to the source and still have enough aerodynamic features that it could fly," Tether explains.

"DARPA did that over the opposition of the Air Force, who understood the value of stealth, but it didn't have the performance of airplanes in the '70s. It was a hard cultural shift—yet they not only have made it, but today the F-22 is not just stealthy but extraordinarily maneuverable, because we have learned how to use both Maxwell's equations and Navier-Stokes to build aircraft. So DARPA really led the way on stealth in the early days, but the Air Force took over in the mid-'80s and has carried it since then."

The Grumman-built X-29 was a typical DARPA X-plane, incorporating a number of new technologies—some intended, some required to make the rest work. It was the first forward-swept wing aircraft to achieve level supersonic flight, but the wing design and canards made it inherently unstable. Overcoming those aerodynamic problems led to the X-29 also becoming a testbed for computerized fly-by-wire controls and for the use of advanced composite materials to create lightweight, rigid wings.

With all that in place, the X-29 exceeded expectations, providing significantly advanced maneuverability in a dogfight. The problem, as defined by Cooper, was that the concept of operations for strategic aircraft was changing, and dogfights were going out of style. Instead of getting close to the enemy, the Air Force and Navy wanted fighters with radars that could detect hostile aircraft and missiles that could engage them long before they could get close enough to be a problem.

As a result, Cooper faced a dilemma: Continue work on an aircraft everyone agreed would be a magnificently maneuverable system for dogfighting, or yield to what was happening in the world and say non-line-of-sight weapons systems in aircraft were the wave of the future.

His solution was typical DARPA: Recognize there might be a future use for the lightweight materials the X-29 required and that developing the design capability for them would be a major advantage in dealing with thrust-to-weight ratios on another program at another time. So the aircraft was built and tested, in a joint program with Germany, primarily to test the concept of vector thrust, used in concert with other control systems to enhance maneuverability. The results of those ex-

X-29

NOTAR

periments and the design information they produced are now standard in today's most advanced operational aircraft.

Another DARPA concept that soon found its way onto production aircraft was the use of a no-tail-rotor (NOTAR) boom on single-engine helicopters. NOTAR helicopters are far quieter—and thus more difficult to detect—than standard designs. DARPA's NOTAR development program in the early 1980s led to the first fundamental change in single-rotor helicopter design since the late 1950s.

The 1980s also saw heavy DARPA involvement in new material technologies for fighter aircraft. One example is the development of multimetal systems with superior temperature and wear characteristics for F-15, F-16, and F-22 engines, using rapid solidification rate processing to create nonequilibrium combinations that otherwise would separate. Another is the use of lightweight ceramic matrix tiles in cargo aircraft.

DARPA-developed metal matrix composites help remove heat generated by advanced, high-density electronics. Silicon carbide-reinforced aluminum, for example, is used in heat sinks in the wiring board core of the F-22's electronic warfare (EW) subsystem, on the power supply subsystem of the F-18, and on similar electronic "hot zones" on the EA-6B Prowler EW aircraft and the Longbow missile.

DARPA has played a major role in keeping the concept of the UAV alive as a military asset. But perhaps no single program advanced that effort so much as the Amber UAV, initiated in 1984 as part of the agency's rapid prototyping program. Developed as the first medium-endurance UAV, Amber was accompanied by DARPA's development of a new high-capability radar for it to carry.

Gnat

The result was the Tier 1 General Atomics Gnat 750, with its 450-lb payload and electrooptics suite, which became the first UAV deployed to Bosnia. The Amber/Gnat 750 design quickly evolved into the Tier 2 Predator medium-altitude/long-endurance UAV, which drew initial interest in the Balkans before becoming one of the military's most valuable assets in the second gulf war.

A decade earlier, the first gulf war had seen another DARPA-initiated effort from the 1980s introduced into military use—the Pave Mover airborne target acquisition weapon delivery radar program. Based on earlier DARPA R&D into a low minimum detectable velocity moving target indication (MTI) radar, Pave Mover provided the technology demonstration for what became the heart of the Joint Surveillance and Target Attack Radar System.

JSTARS was another program requiring Army, Air Force, and DARPA agreement on what kind of system needed to be built, what capabilities it would have, how it would fit in with existing Air Force and Army assets and so on, according to Cooper. With those details ironed out, the system not only was built and tested, but proved so effective that the developmental aircraft was deployed to Iraq during Operation Desert Storm.

Predator

DARPA's typical process—developing something in one decade that leads to something with greater direct military application two or three decades later—was demonstrated by the Tethered Aerostat Radar System. TARS, which began operations in the mid-'80s, evolved directly from

JSTARS

DARPA's Egyptian Goose radar balloon and Grand View communications balloon payloads in the 1960s, and from Pocket Veto and Seek Skyhook in the 1970s, both used to monitor Cuban aviation.

Comprising a large tethered balloon equipped with a high-power, long-range MTI radar and communications package, TARS was operated jointly by the Air Force, Army, Coast Guard, and Customs to monitor the U.S. coastlines and southern border for low-flying aircraft used for drug smuggling and other illegal activities.

That "before its time" aspect of its programs is one of the agency's greatest strengths. But directors soon discovered it also can be a major liability if outsiders give it too much visibility, too much hype.

Perhaps the greatest example of that was the National Aerospace Plane. NASP was intended to use supersonic combustion ramjets (scramjets), which operate with hydrogen and oxygen scooped from the air in flight, to drive a sizable aircraft up to orbital velocity or enable it to fly at altitudes as high as 200,000 ft at supersonic or even hypersonic speeds. The resulting ability to have global reach very quickly was extremely attractive for both military and civilian aviation.

DARPA instituted a program with all the anticipated elements it needed to conquer in order to design, build, and test a prototype aircraft. That included engine development as well as creation of new

kinds of materials and new design techniques that would prevent the aircraft's self-destruction from the heat of friction as it moved through the atmosphere.

In three years of fundamental research, DARPA spent about $700 million-$800 million and pushed forward to a point where Cooper believed another three or four years would make it possible to build and test such an aircraft. It was at that point, however, that the problem of over-heightened visibility came into play.

During Cooper's last year, President Reagan became intrigued with the concept of a 737-size airplane that could cruise at 150,000 ft. In his State of the Union address, he called it the Orient Express, because theoretically it could fly from New York to Japan in under an hour. Giving NASP such a high profile, however, also put it under intense public and political scrutiny—which DARPA directors have said is rarely helpful to the kind of beyond-cutting-edge research the agency does. The result was that funding for NASP quickly fell to Pentagon budget-cutters.

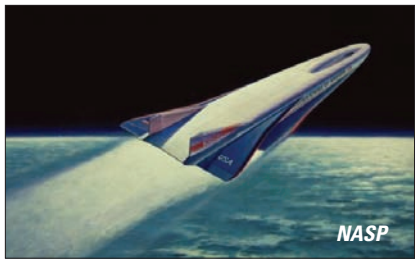
This left the question of whether, had the funding levels of the early 1980s continued, the program would by now have delivered aircraft that could fly into space from a conventional runway or perhaps race around the globe in a matter of minutes. Cooper has said he believes it well could have, but others believe NASP was simply too far ahead of its time.

"Our greatest crossover between aircraft and satellites is our desire to develop a vehicle that looks like an aircraft, could take off horizontally, fly into space, and come back. We've had that dream for a long time; you can find studies of that going back to the '60s," Tether says today.

"In the early middle '80s we started NASP and took it as far as one could, but basically materials got in our way. There are a lot of technologies that had to be done to do that, so we pushed everything as hard as we could and realized there were still a lot of fundamental things that had to be done."

ROCKETS AND MISSILES

While the cruise missile can trace its origins back to first-millennium China, many of the technologies in today's stealthy, long-range precision systems evolved


NASP

from DARPA programs going back more than four decades.

The joint DARPA/Army Individual Mobility System project of the late 1960s helped develop turbofan technology that evolved further through the following decades to power all current U.S. cruise missiles. But it was DARPA's stealth programs that lifted the cruise missile concept to a new level in military applications.

Teal Dawn was such an effort, drawing off past DARPA low-observables programs for the design of low-signature engines and angled surfaces. Before it was turned over to the Air Force and incorporated into the Advanced Cruise Missile, DARPA and Air Force tests sponsored by the agency validated signature, range, and flight profile goals.

One of the smaller missiles in the legacy was the man-portable Javelin anti-tank missile, with elements derived from DARPA's Tank Breaker concept of the late 1970s and early 1980s. As Soviet armor became increasingly tougher against a frontal assault, DARPA combined lock-on before launch and an imaging focal plane array seeker with a warhead designed to strike at the tank's vulnerable top surface.

In addition to long-wave IR thermal target acquisition and missile seeker array manufacturing technology, DARPA called on two decades of mercury-cadmium-telluride technology development and its MCT Manufacturing Technology Program to provide the manufacturing yield needed for Javelin's IR imaging array, reducing production costs for both seeker and target acquisition arrays by 99%.

1990-1999

SPACE

Many of DARPA's space-related efforts in the 1990s were devoted to small satellites and their launch systems.

Taurus

The Pegasus air-launched vehicle was developed to provide a quick-response tactical satellite capability, using a B-52 bomber as the launch platform from which Pegasus could boost 450-lb payloads into LEO. The first launch, on April 5, 1990, was a three-function payload comprising an experimental Navy communications relay satellite, a NASA barium experiment, and instruments providing data on the launch itself. After a second successful flight, Pegasus was transitioned to the Air Force on April 23, 1993.

Pegasus

The Taurus small standard launch vehicle was developed in conjunction with the LightSat concept to enable the rapid launch of small tactical satellites from undeveloped sites within or close to a battle theater. With its own transportable launch platform and associated hardware and systems, Taurus was designed to be moved into place, set up, and launched within a week. The solid-propellant launch vehicle used a Peacekeeper missile first stage and a modified Pegasus missile as its second, third, and fourth stages, enabling it to lift a 1,900-lb payload into a 400-n.mi. polar orbit.

The first Taurus launch, from Vandenberg AFB on March 13, 1994, placed the second agency contribution to this concept, the 447-lb DARPASAT, and a comanifested Air Force experimental satellite into

a roughly 325-mi. medium Earth orbit. The DARPASAT carried GPS receiver and data processor technology tests.

Another small satellite study led to development of DARPA's Starlite concept. This constellation of low-cost radar satellites would provide 24-hour all-weather synthetic aperture radar imaging warfighters could task as needed and downlink directly to theater. Working with the Air Force, DARPA modified Starlite to include space-based high range resolution ground moving target indication capabilities similar to those in JSTARS.

In 1998, a task force created at the request of DARPA, DOD, and NRO recommended initiation of a modified Starlite program, later designated Discoverer II, to provide broad-area, all-weather, near-continuous military space radar surveillance. The program was canceled by Congress in 2000, but it retained sufficient interest from the services and the incoming Bush administration to become the foundation for a new space-based radar program.

AVIATION

The Affordable Short Takeoff/Vertical Landing (ASTOVL) program, later renamed the Common Affordable Lightweight Fighter technology demonstration program, sought to take the capabilities of the Marine Corps AV-8B Harrier jumpjet and V-22 Osprey tilt-rotor to a new level. Initially the idea was to provide two variants—a STOVL fighter for the Marines and a conventional takeoff and landing derivative for the Air Force. But the program soon was expanded to include a carrier-capable version for the Navy.

X-31

The original DARPA effort involved three phases. The first, completed in September 1991, looked at the STOVL in terms of airframe design and the application of a derivative of the Advanced Tactical Fighter

Common Affordable Lightweight Fighter

engine. The second, completed in March 1996, involved analyses of affordability, airframe design, and critical technology validation. Before Phase III was begun, the effort was transferred to the DOD Joint Strike Fighter program, and results from the DARPA studies were incorporated into the triservice F-35 Lightning II.

Another DARPA EEMIT program was the X-31, initiated in cooperation with the German air force to design, build, and test a highly maneuverable close-combat fighter. The aircraft's enhanced maneuverability elements included several aeronautic and military aviation firsts: integration of conventional aerodynamic control with multiaxis thrust vectoring, demonstrating the feasibility of post-stall flight, tailless flight at supersonic speeds, an advanced helmet-mounted display to improve pilot situational awareness, digital fly-by-wire flight controls, and significant advances in high-angle-of-attack performance.

Between October 1990 and June 1995, when the program ended with demonstration flights at the Paris Air Show, the X-31 conducted 580 flights involving 14 pilots. It is considered a major DARPA success.

An outgrowth of DARPA's Small Engine Advanced Program (SENGAP), the Miniature Air-Launched Decoy (MALD) program sought to develop a small expendable air-launched decoy to confuse enemy surface and airborne air defense systems. The resulting enhanced "fog of war" would improve the survivability of friendly aircraft and the establishment of air superiority. Equipped with SENGAP's 50-lb-thrust turbojet engine, the TJ-50, the MALD made its first successful flight from an F-16 in January 1999. The test and evaluation program continued through 2001, and subsequent MALD variants have remained in development since then.

It was also in the 1990s, DARPA believes, that UAVs finally moved from their uneven history, created by cultural anathema rather than any serious technological limitation, to become a major military asset with ever-growing demands to push capabilities even further.

2000-PRESENT

SPACE

Tether recalls, "In 2001, space again became a great DARPA program because, as in the beginning, both the president and secretary of defense were interested in DARPA doing something in space. Before he became secretary, Donald Rumsfeld created the Space Commission Report, and DARPA was directed to execute that, which is why we went from an expenditure on space of a couple of million dollars in 2000 to close to half a billion dollars in 2007."

Early in his tenure, Tether created a Virtual Space Office (VSO) at DARPA, virtual because it has no office director—program managers from throughout the agency get together by themselves to pursue common goals. Creating a typical office would have been counterproductive, he believes, because space permeates the entire organization, and putting all of the space-focused researchers into the same physical structure would have been extremely disruptive.

"DARPA investment in space-related technologies has increased significantly and is spread over five strategic thrust areas, namely: access and infrastructure, space situational awareness, space mission protection, space mission denial, and space-based support to the warfighter," said Steven Walker, one of VSO's program managers, at DARPATech 2007.

The successful January 11, 2007, Chinese antisatellite test was the same kind of

SpaceX Falcon

wake-up call the U.S. experienced with Sputnik a half-century earlier, Walker added—and DARPA needs to respond as it did then: "Rather than react to surprising events of the future, we need to design flexible space architectures now, so that we are prepared for the future. That is to say, we need space capabilities that are more responsive, more robust, and can be modified easily as threats arise.

"When it comes to putting spacecraft in orbit, we envision reusable and responsive launch systems that can take off and land at today's airports, just like airplanes. These vehicles would use air-breathing, combined-cycle propulsion systems that are being developed now in the FALCON [Force Application and Launch from CONUS] hypersonics program," he said. "In the interim, we are demonstrating affordable and flexible expendable launch capabilities for small satellites. We recently launched a Space-X FALCON 1 rocket from a small island in the Pacific, clearly demonstrating the ability to launch with minimal infrastructure quickly and cheaply."

Evidence of DARPA going—and succeeding—where others may not follow for years to come can be seen in 2007's Orbital Express Space Operations Architecture program. Designed to test whether two satellites can rendezvous in orbit and exchange liquid fuel, batteries, and even system upgrades, Orbital Express proved a success even when the sensor flight computer on the maneuverable service satellite failed. A second computer, originally meant for transfer to the target satellite, was instead activated to replace the failed unit, and DARPA was able to complete nearly all of its remaining mission.

Orbital Express attracted considerable interest from both civil and military satellite users. However, it may be some years before either community works out the practical applications and cost efficiencies of on-orbit satellite servicing.

Orbital Express

DARPA also continued its pursuit of hypersonic cruise by seeking to develop scramjet technology that would be appropriate for the Air Force's FALCON program. The goal is a vehicle with intercontinental range and cruise speeds up to Mach 10, able to operate with or without humans on board and as a space launch system, as well as to deliver payloads—including weapons—point-to-point on Earth.

Also under development with the Air Force is the Space Surveillance Telescope. This ground-based system will focus on locating faint objects in deep space for both asteroid detection and space defense missions. Plans are for its transition to the Air Force Space Surveillance Network at the end of Phase II testing in 2009.

In another program, called F6, DARPA is looking at the concept of networking many small satellites, to exceed the capabilities—and reduce lifetime costs—of a single large platform.

"With F6, we intend to demonstrate that we can decompose a large monolithic spacecraft into a group of wirelessly linked elements or nodes. Each node executes a specific spacecraft function. One, for example, might be a computing node, another a payload node—like a transponder or an intelligence sensor," said Owen Brown, another VSO program manager, in an address at DARPATech. "These nodes, operating together, create a single 'virtual' spacecraft.

"F6 offers great flexibility. Let's say you wish to upgrade a spacecraft with a new, faster computer. The solution is to fly a new module that performs just that computing function into the cluster. The virtual spacecraft will then seamlessly integrate this new capability into the network. By decoupling—or fractionating—various parts of the spacecraft, we can reduce fragility and implement new flexible design and acquisition paradigms.

"Using this approach," Brown continued, "satellites in the small, micro, nano, pico, and even femto scales can be taken out of the boutique and become part of the mainstream. As the foundation of a new architecture, small satellites could eventually play a primary role across the full spectrum of planning: tactical to strategic; theaters, local to global; orbits, LEO to GEO; and mission timescales, hours and days to undefined ends."

X-45

AVIATION

The second gulf war has significantly increased acceptance of and, ultimately, demand for UAVs. Yet some at DARPA felt it still was an invention that would not achieve the status of innovation until the services changed their way of doing business—essentially, a marriage of the invention and an operational concept that people are then trained to do. This requires convincing an organization to change to something new from something at which they have spent years becoming efficient.

From hand-held versions to Global Hawk, the growing fleet of UAVs emerging from DARPA's efforts is well on its way to achieving that goal, with increasing successes in Iraq and Afghanistan as well as applications around the world.

But DARPA's years in the hot-seat—between the services, the White House, and Congress—have demonstrated that even success is not always a guarantor of future program survival.

For example, from October 2003 to November 2005, DARPA managed the Joint Unmanned Combat Air Systems program in concert with the Navy and the Air Force. Two prototype test vehicles—Boeing's X-45 for the Air Force and Northrop Grumman's X-47 for the Navy—were built before the program transitioned to a joint Navy/Air Force office, only to be canceled about a year later, although the Navy has continued its effort independently.

A-160

DARPA's A-160 Hummingbird rotary UAV program, conducted with Boeing Phantom Works, has been pursuing a number of new UAV and helicopter capabilities since the aircraft's first flight in January 2002. With a 36-ft-diam variable-speed hingeless rotor and 35-ft fuselage, the turbine-powered A-160T is designed for speeds up to 140 kt, high hover at 15,000 ft, and a ceiling up to 30,000 ft (about 50% higher than most current helicopters). Flight tests in 2007 with a 500-lb payload indicated the A-160T could meet its target 2,500-n.mi. range and 24-hr endurance goals.

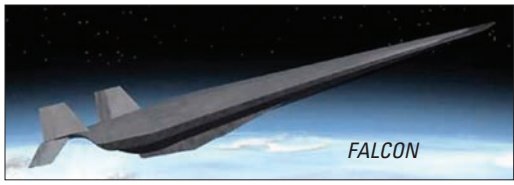
Anticipated missions include persistent ISR, target acquisition, lethal and nonlethal weapons delivery, communications relay, and precision resupply. Potential users include the U.S. and international military—particularly special forces—and the Dept. of Homeland Security. DARPA also is investigating the use of more efficient heavy fuel engine technologies to further extend range and endurance. An A160-T with a modified pod is to be delivered in 2009 for DARPA's ARGUS-IS (Autonomous Real-time Ground Ubiquitous Surveillance-Imaging System) program.

As with the X-wing two decades earlier, the X-50 Dragonfly was an attempt, with Boeing Phantom Works, to develop a canard-rotor wing that could stop the rotor in flight, turning it into a fixed wing capable of high-speed flight. Unlike that earlier craft, which was never flown, the X-50 used the canard and wing to support the weight of the unmanned aircraft and make the conversion with the rotor unloaded. The program faced cancellation after the first two platforms were lost in crashes in 2004 and 2006.

While FALCON is essentially a space/-missile program, it also has given rebirth to another old DARPA dream in aviation: hypersonics.

"For the past 15 years, we've been working on the fundamentals—materials that can survive high temperatures, engines that can have positive thrust at zero forward velocity, yet change their mechanisms as they go through the various regimes, finally getting up to Mach 10," Tether says. "We're just starting a new program called Black Swift, which is in the president's upcoming budget. It is split evenly with the Air Force.

"The initial version will be unmanned, which avoids a lot of man-rating that is really more cost than technology. We'll have an airplane that can take off, fly up to Mach 6, turn around and land again. It also will be designed to do an aileron roll at Mach 6 at 100,000 ft, which separates it from a missile.


FALCON

"Mach 6 is just a step. Once we get there, we'll be back on the NASP path, maybe a little bit more cautious in terms of time to get to Mach 25. We'll demonstrate the unpowered version by flying two hypersonic test vehicles into Kwajalein in 2008. Black Swift will take full advantage of that," says Tether.

As DARPA has pushed the envelope on new aerial platforms, it also has worked to develop advanced sensors, avionics, and other component systems for them.

One such current example is the Low-Altitude Airborne Sensor System (LAASS) program, which is developing improved

X-50

intelligence, targeting information, and battle damage assessment tools. The goal is to enhance significantly the ability to find and classify hidden or underground facilities, tunnels, and power-grid infrastructure using passive electromagnetic, acoustic, and gravity gradiometer sensing. Sensor and signals processing payloads developed under LAASS will be integrated and tested on both low-altitude UAVs and manned aircraft.

And, in keeping with DARPA tradition, some research spans multiple potential applications, such as the Defense Science Office's "Programmable Matter."

"Programmable Matter is a user-programmed smart material that adapts to changing conditions in order to maintain, optimize, or even create a whole new functionality, using means that are intrinsic to the material itself," DSO program manager Mitchell Zakin explained at DARPATech. "From a military perspective, Programmable Matter is the ultimate way to prevent technological surprise—by having materials, such as polymers, metals, or composites, adapt to future operational environments.

J-UCAS

"From Programmable Matter, we could build materials and even smart machines that adapt to their surroundings, such as an airplane wing that adjusts its surface properties in reaction to environmental variables. We would no longer be constrained by the installed version of a system—constant feedback from the operational environment would ensure that we always have the latest capabilities."

"In aviation, it's easy to talk about most of the achievements of the past, but a lot harder to talk about the dreams of the future, because we do a lot of black programs. We were created to prevent technological surprise, but we've also become the place that creates technological surprise for other people."

Tony Tether, DARPA director

2058

For the past half-century, DARPA has been at the center of—and, more often, far in the lead on—some of the biggest technology concerns and breakthroughs in U.S. and world history.

Created as the U.S. spearhead at the start of the space race with the Soviet Union, it was quickly given the task of detecting nuclear weapons tests and defending against ballistic missiles. Its legacy includes everything from the creation of the science of seismology to the discovery of plate tectonics (an outgrowth of Vela) to UAVs, stealth, hypersonics, launch systems, satellite navigation and communications, small satellites, airborne ground target tracking, advanced avionics, new approaches to both fixed-wing and rotor design and operation, new aircraft materials, and much more.

By going where others could not—or would not—go, DARPA has been one of the world's most consistent and preeminent contributors to revolutionary advances in aerospace.

It is the one government agency for which failure can be as much a positive as a negative—as long as it results from reaching too far and not from mismanagement—and where being impossible is considered a challenge rather than a roadblock. It has a constant turnover in both program managers and directors to avoid the "we tried that, it didn't work" syndrome. For all these reasons, it is likely DARPA will continue for at least another 50 years.

"You can't kill good ideas, although you can stop them for awhile. But they come back, especially at a place like DARPA," Tether notes with pride. "We rotate our people through here in no more than six years—which is great, because that means 10 years from now someone can come in with an idea we tried before that didn't work, but there won't be anyone around to say that. That's what makes us different from anyplace else."

In its first half-century, DARPA often found itself at odds with widely accepted scientific and engineering concepts, with its own military customers, with a political bureaucracy that wanted quick results, and even internally, among successive directors. But with a charter to create technological surprise before anyone else, to push the limits between what can be imagined and what can be accomplished, it is unlikely that the agency will soon exhaust its supply of DARPA-hard problems to tackle.

When asked about its prospects for the future, Tether voices no doubt whatsoever on that score:

"The question, I think, is how big will it be. And having a lot of money, which we have, is not necessarily the right answer. A lot of people think I'm nuts, [but] I would rather not spend it if we didn't have DARPA-like ideas to work on. I believe that there always will be a frontier. Teleportation is still there, still unsolved. Now that is a DARPA-hard program. And, you know, we're still working on it."

J.R. Wilson