DARPA PAVES THE WAY FOR U.S. EFFORTS IN BALLISTIC MISSILE DEFENSE

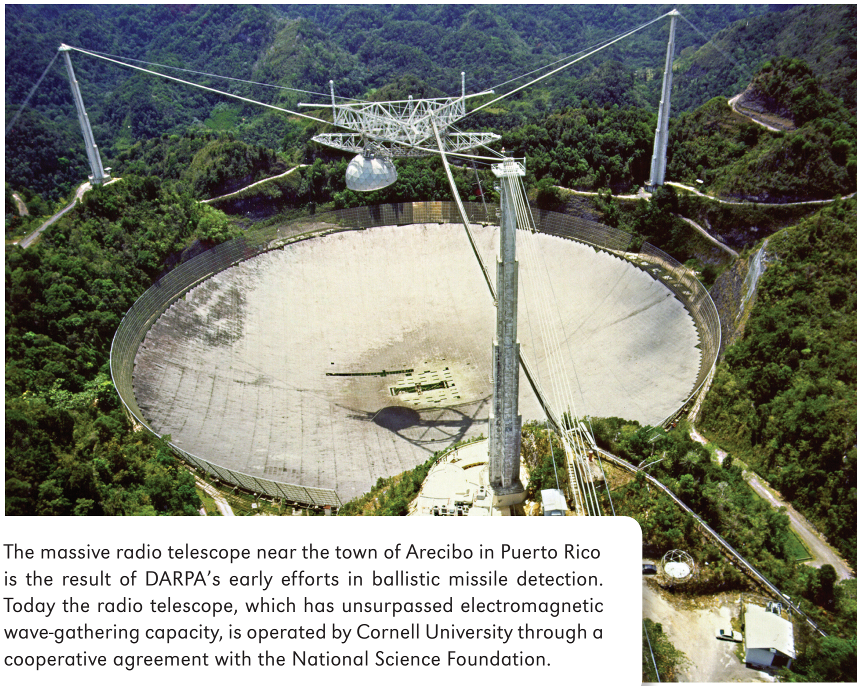
By Barry Rosenberg

For the U.S. military, the 1960s and 1970s were not necessarily defined by the Vietnam War, but by the Cold War between our nation and the Soviet Union. The major instrument of that threat was nuclear-tipped ballistic missiles.

The U.S. Army and Air Force, in particular, had trouble coordinating their response to some of the major military challenges of the time – especially the space program and ballistic missile defense. Recognizing the need to create a single manager that would be immune to inter-service competition and who would focus solely on accomplishing goals from a technology development standpoint, President Dwight D. Eisenhower tasked the Advanced Research Projects Agency with finding a way to protect the nation from nuclear attack.

Ballistic missile defense (BMD) had been part of what was then known as ARPA's charter since it was established in the shadow of Sputnik in 1957. In fact, BMD was consistently ARPA's large budget item in its early years.

ARPA's spirit of intellectual curiosity and technical excellence continued after the word "Defense" was added to the agency's name in 1972. The BMD work it accomplished in those years has lived on in the individuals that later made up the Strategic Defense Initiative Organization (SDIO) and the Ballistic Missile Defense Organization (BMDO). Today, the Missile Defense Agency (MDA) continues to build on the groundwork laid by DARPA.



The massive radio telescope near the town of Arecibo in Puerto Rico is the result of DARPA's early efforts in ballistic missile detection. Today the radio telescope, which has unsurpassed electromagnetic wave-gathering capacity, is operated by Cornell University through a cooperative agreement with the National Science Foundation.

Photo courtesy of the NAIC – Arecibo Observatory, a facility of the NSF

THE CHALLENGE OF BALLISTIC MISSILE DEFENSE

It was DARPA's job to define the problem, answer the questions, and design, develop, and test the technologies that would make ballistic missile defense feasible.

"The Ballistic Missile Defense program was really a huge program ... poorly organized and poorly thought through," said Charles Herzfeld, who was manager of the Defender ballistic missile defense program from 1961 to 1962, and who also served as DARPA deputy director from 1963 to 1964 and agency director from 1965 to 1967. "It [was] trying to do everything – some were sensible things, some were less so. The main task was to get a handle on what the problems were, what it made sense to do."

The first question that the agency tackled was the most logical, but far from the easiest to answer: How do you know that a missile or missiles have been launched at the United States? The answer came with two elements.

The first was the construction and launch of satellites designed to scan the Earth for the infrared signature of a missile plume. The infrared signals were picked up by satellite sensors and relayed back to the ground. The second was the building of radar sites across the United States to detect missiles coming in from over the North Pole. Because the nation also had to worry about missiles launched from submarines, these radars had to provide 360 degrees of coverage.

Next came the process of understanding how a ballistic missile acted in the atmosphere, and differentiating it from other natural occurrences so the country's leadership would know definitively whether or not an attack was truly in progress.

"Missiles make a big signature in the sky," said Herzfeld. "You might be able to tell that it is a real missile warhead, or maybe it is something else. So, you have to estimate how much energy is going into that plume.

One of DARPA's early projects in missile defense was the construction of several radars on Kwajalein Atoll. One task for the radars was to track test missiles and observe how they interacted with the atmosphere. In this photo three bright streaks of light mark missile reentries into the atmosphere above Kwajalein.

DoD photo

That means you have to understand the chemistry of what's going on, and you're right away deep into studying chemical reactions in space, something that you couldn't easily produce in a laboratory.

"Then the next question is, what do you do about it? Well, there are two or three layers you have to address. First of all, you have to tell the president – very fast – and the system was set up to do that within minutes. You could inform the president within, say, five minutes. A mechanism was also set up so he could get his principal advisors like the secretary of defense into the loop for a quick conference.

"Then, finally, do you want to shoot back and explode the incoming missile before it hits anything? So you get into the interceptor business, which raises other questions: Where do you place them? How big are they? How fast do they have to be to get there in time? All that turned into, let's say, a thousand different, little projects – some of which were very expensive."

One of those projects was the construction of several radars on the island of Kwajalein in the Marshall Islands. The primary job of those radars was to look at our own test missiles and observe in detail how they interacted with the atmosphere. The radars were the key element of a national center for ballistic missile testing established at the atoll by the Department of Defense. Long-range ballistic missiles were fired for testing purposes from Vandenberg Air Force Base in California, while shorter-range missiles were launched at Kwajalein from submarines and from Wake Island. Information gathered by the Kwajalein radars during those tests helped to hone the military's early BMD efforts.

For the scientists, engineers, and researchers at DARPA it was a complicated and difficult but also a wonderful and exciting time. Nobody knew for sure exactly what would work, what wouldn't, and what unexpected results would come from the work that they were doing.

One unanticipated development came from the construction of a powerful radio telescope in the mountains about 9 miles from the town of Arecibo in Puerto Rico. Scientists thought that missiles passing through the ionosphere about 50 miles high would create waves within the ionosphere that could be detected. Arecibo was built for that job.

The observatory's 305-meter main collecting dish is the largest single-aperture telescope ever constructed. It is also the largest curved

DARPA research and development supported the Sentinel and Safeguard ground-based interceptor programs in the era prior to the 1972 Anti-Ballistic Missile Treaty. Below: A Sprint missile launch. Sprint was an engineering marvel, reaching such speeds that the missile's skin became incandescent, exceeding the temperature of its rocket motor. Right: A dual launch of Spartan missiles from Kwajalein Atoll. Spartan and Sprint missiles were paired in the Safeguard system.

Courtesy of SMDC/ARSTRAT

focusing dish in the world, which gives Arecibo unsurpassed electromagnetic wave-gathering capacity.

"By the time I came to ARPA, two things were already clear," said Herzfeld. "One, it was probably not the most important thing we could do for ballistic missile defense. But, two, it was an absolutely marvelous radar telescope to look at other stuff.

"Many people wanted me to kill this, but I didn't because I thought there was really very interesting stuff being done – for military and for scientific reasons. This has been an amazing success."

Today, Cornell University operates the Arecibo radio telescope under cooperative agreement with the National Science Foundation.

"So many things happened serendipitously that were not of top importance, but had wonderful side effects," said Herzfeld.

Another of the original BMD projects still paying dividends is the ARPA Maui Optical Station (AMOS), which initially served as a facility for operational measurements and research and development related to space object identification and tracking in the early 1960s.

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

Regardless of whether DARPA researchers fully understood the ultimate benefit of the technologies that they were creating, it is clear that they were establishing a framework for research and development that had only one purpose – improving both the offensive and defensive capabilities of the U.S. military.

"One of the interesting hallmarks of ARPA from early on is that even though we were all finding our way, we would always start from a military problem," said Herzfeld.

"With missile defense there were a whole series of technical things that needed to be understood. Most involved brand-new science that had never been done, or never been done as accurately, or as quickly, or as conveniently, like out on a range or from an airplane.

"We learned how to do that. We learned that you needed communications that were very robust and very fast. We learned that we had to have very good telescopes. We had to have very good, very fast interceptor missiles. Each large military problem was broken down into smaller military problems, and each of these was attacked – first in the lab and then on the range. Ultimately you have something that you can give the troops."

DARPA's primary BMD program of the 1960s was Project Defender. Its goal was to develop orbiting platforms from which conventional (or nuclear) missiles could be launched and then detonated at high altitude to knock down Soviet ballistic missiles. There were also studies into launching wire mesh from the platforms to disable missiles in their boost phase. Other than the obvious technical challenges associated with building orbiting launch platforms, Defender was unable to defend itself from attack, which ultimately led to its cancellation in the late 1960s.

A number of other programs followed, including Sentinel and Safeguard, which combined ground-based radar and missiles to destroy enemy missiles. Exploding defensive warheads over home territory, however, was problematic from a political standpoint.

All of those programs became moot in 1972 when the United States and the Soviet Union signed the Anti-Ballistic Missile (ABM) Treaty, which permitted only a single ABM system to protect just one target.

BMD WITH DIRECTED ENERGY

"1978 to 1984 was a very exciting time," said Joseph Mangano, who was deputy director of DARPA's Directed Energy Office at the time and today is a program manager in the agency's Microsystems Technology Office. "We were in the middle of the Cold War. On becoming president, Reagan discovered that his options in a case of ballistic missile attack were limited to launching an all-out attack, as in Mutually Assured Destruction, or to have no response at all. He, like a lot of people, [was] surprised to find that there [was no] real defense against ballistic missile attack."

At the time, the only BMD-type program the nation had was an interceptor missile being developed by the Army.

"We had very few options in the sense that the technology was not developed to the point where it could be deployed," said Mangano. "The interceptor approach was all we had, and if you were talking about a small number of launches mustered by a small, nuclear-equipped nation, then that might be adequate. But it could not handle a saturation attack with all manner of decoys and chaff to confuse the defense. The only way to potentially handle such an attack would be to negate the ballistic missiles in the boost phase and before the multiple independently targeted warheads, together with decoys and chaff, separated from the bus. Once the warheads and decoys separated, the problem became much more difficult as they were much more likely to saturate the midcourse and terminal phases of the defense system. It was felt that speed-of-light weapons had potential for boost phase kill."

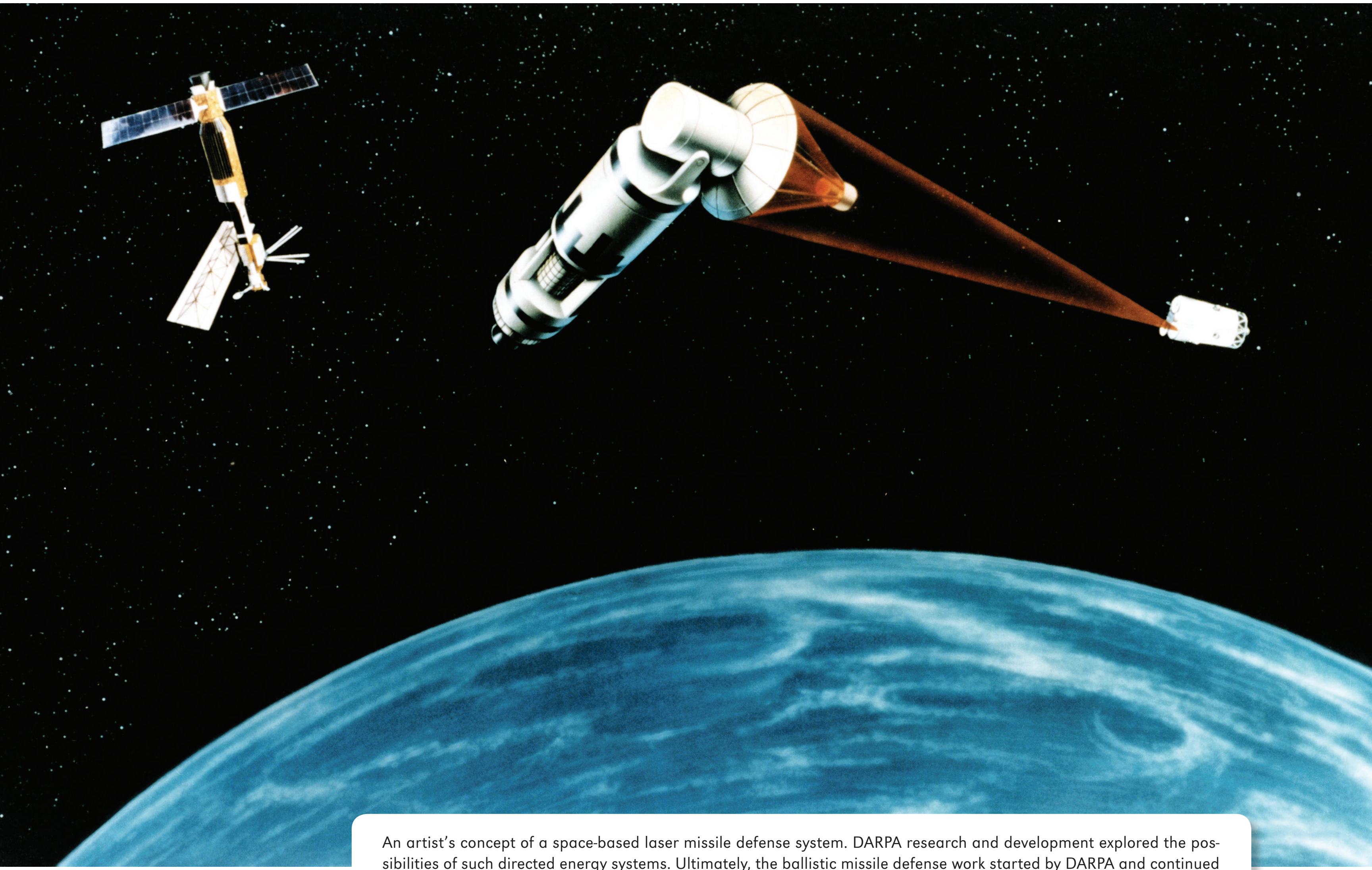
From that reality came DARPA's initial research and development into a space-based BMD system using directed energy. This system was later expanded to include ground-based lasers with their beams projected into space and vectored around the globe with high-altitude relay mirrors and lower-altitude fighting mirrors. The problem, of course, was that global coverage was needed, and that required a very expensive constellation of either laser satellites or relay mirrors.

Similarly to how the agency had been tasked nearly two decades earlier, DARPA was once again charged with the job of leading the nation's latest BMD initiative from a strategic point of view.

"You can quibble or debate whether such a defense was possible or not, but we knew we had to explore the possibilities," said Mangano. "In the end, DARPA was exploring the limits of these technologies and whether in the end game, this technology could play. I doubt that serious researchers at the time believed that this system could provide a total, leak-proof defense against ballistic missiles."

In fact, many people thought that such a system was technologically unfeasible. DARPA researchers, though, have always thrived on such challenges.

"It's much easier to play offense then defense. On defense, you have to prepare for every eventuality in time and space,



An artist's concept of a space-based laser missile defense system. DARPA research and development explored the possibilities of such directed energy systems. Ultimately, the ballistic missile defense work started by DARPA and continued by the Strategic Defense Initiative Organization, the Ballistic Missile Defense Organization, and the Missile Defense Agency has served to secure the future of the United States and the safety of its citizens.

while on offense you just have to pick one and attack," said Mangano. "The prospects of developing such a defense, in which 'leakers' were not allowed, was daunting. But the whole point of DARPA was to either prevent technological surprise or to create technological surprises. So we went out to determine what was possible technically."

The concept of "DARPA hard" has been instilled in those who have labored there since 1958.

"Someone who says something can't be done and can't prove it is someone to be avoided by the people at DARPA," said Mangano. "You've got to fail some fraction of the time or you're not pushing the limits far enough. And DARPA, unlike most agencies, is allowed to fail some fraction of the time."

DARPA's directed energy efforts focused primarily on knocking down missiles in the boost phase so the destroyed missile and its nuclear material would fall back onto the enemy's home territory, though technologies were also being developed, primarily by the Army, to strike missiles in the midcourse and terminal phases.

The agency built a number of high-powered lasers before responsibility for BMD shifted to the SDI organization. All were chemical lasers that employed either hydrogen fluoride or deuterium fluoride to generate the laser beam.

DoD imagery

The Alpha High-Energy Laser was DARPA's primary laser program at the time. The goal was to develop a demonstrator that could over time be scaled to one that would provide the multi-megawatt-level power necessary for ballistic missile defense. Alpha followed on earlier work DARPA and the Navy conducted with the Mid-Infrared Advanced Chemical Laser and other chemical laser systems. In the early 1990s, after the Alpha program transitioned to BMDO, the laser did indeed demonstrate multi-megawatt space capability.

Other programs at the time included Talon Gold, a beam director program to acquire, point, and track the laser; a project called LODE to build large optics for the space-based laser; and another program to develop space mirrors that would have allowed the laser to remain on the ground.

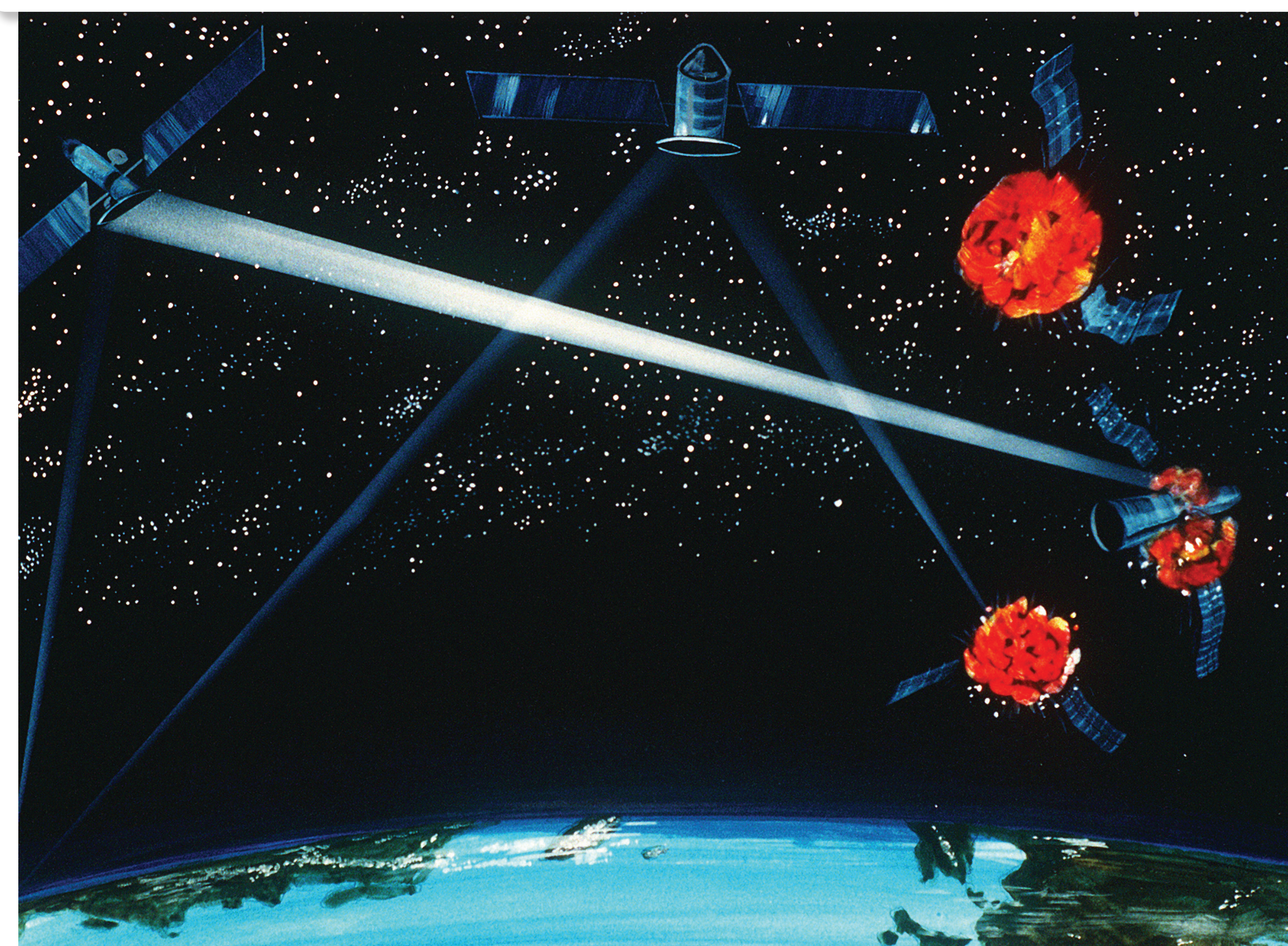
"Lasers have evolved since then," said Mangano. "In those days these high-power lasers operated in the mid-infrared region of the spectrum, and the mirrors required to obtain small spot sizes at the target were of quite large diameter. But we did show you could scale lasers to very high power and have a large enough final optic to efficiently deliver a narrow beam over thousands of kilometers and deliver a small, very intense spot to the target."

In the same fashion that BMD work done by an earlier generation at DARPA paid dividends in unexpected places, some of the directed energy work from the 1980s has found life in new applications.

For example, DARPA researchers invented and refined rare gas halide excimer lasers in the 1975-1985 time frame. These ultraviolet lasers were the first that were efficiently scalable to high power, and it was hoped that the technology would lead to a narrower beam that could efficiently deliver power to targets at even greater ranges. The laser didn't pan out for defense purposes, but over the last decade the technology has found a home in the manufacture of all state-of-the-art commercial integrated circuits with deep-ultraviolet lithography and in eye surgery (lasik).

In another example, laser guide star technology was invented to allow ground-based lasers in the visible and ultraviolet spectral regions to image and deliver power to uncooperative space targets despite the effects of atmospheric turbulence. This laser guide star technology is

An artist's concept of a space laser missile defense system using ground-based lasers with their beams directed to orbiting mirrors.



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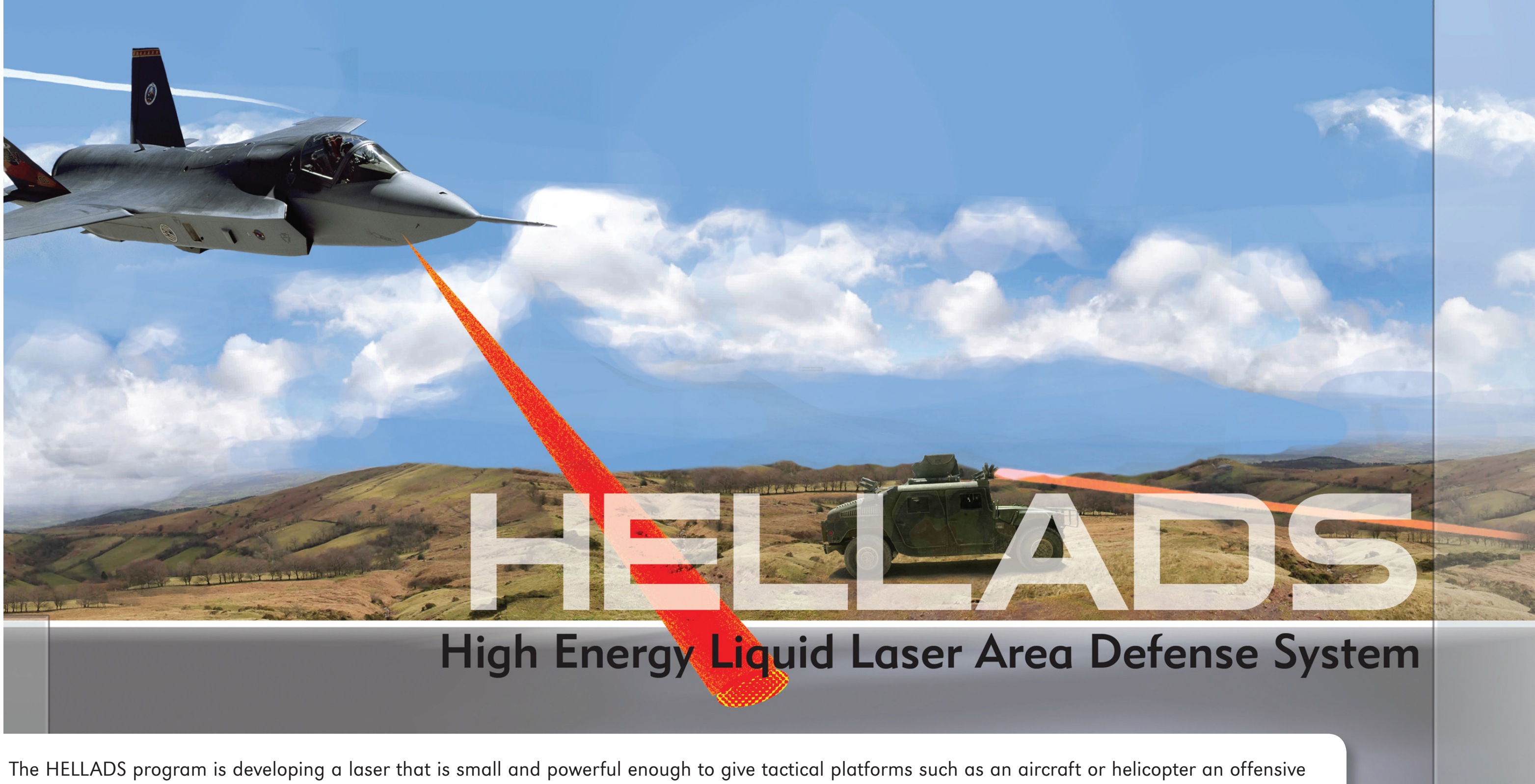

The HELLADS program is developing a laser that is small and powerful enough to give tactical platforms such as an aircraft or helicopter an offensive and defensive laser weapon.

Image courtesy of DARPA

now used on many ground-based telescopes in astronomy to provide high-resolution imaging of space objects in the visible region of the spectrum.

PLAYING A KEY ROLE IN THE END OF THE COLD WAR

Ultimately, the ballistic missile defense work started by DARPA and continued by SDIO, BMDO, and MDA has served to help secure the future of the United States and the safety of its citizens. The people who worked on those programs then, and those who continue to work today understand the political questions and uncertainties that swirl around the issue of ballistic missile defense. However, the job of scientists and researchers at DARPA is to develop new military technologies and capabilities without allowing politics to get in the way.

"The real question is, if you are threatening me with a ballistic missile system – hundreds of them, thousands of them – what's my point in building a defense if I know that one or more will get through?" asked Herzfeld. "The answer hinges on the details, because you won't be able to be absolutely sure that you'll succeed with your attacks, because of my defense, and vice versa.

"So, it raises uncertainty on both sides, and uncertainty cannot be overcome by a first strike. So, it's very stabilizing. In fact, defenses are highly stabilizing, and people who think they are destabilizing haven't understood the problem. Should I have a little shield just in case you have a sword? The answer is, you bet. Maybe you'll think a lot before you draw the sword. That's the point of defense."

Said Mangano: "In terms of money, it was difficult for the Soviet Union to develop their own ballistic missile defense based on directed energy. An overwhelming offensive capability was in place. To make that impotent and obsolete would have taken a lot of money.

"In a real sense they gave up and that was the start of the dissolution of that union. Our efforts at DARPA played a not insignificant role in ending the Cold War. And this war was ended in a very efficient manner, with only a modest, less than 1 percent, expenditure of the defense budget, and with no loss of life."

THE HIGH ENERGY LIQUID LASER AREA DEFENSE SYSTEM (HELLADS) PROGRAM

The spirit of DARPA's early directed energy research still exists today in the High Energy Liquid Laser Area Defense System (HELLADS) program.

The goal of the HELLADS program is to develop a high-energy laser weapon system (~150 kW) with an order of magnitude reduction in weight and volume compared to existing laser systems, and with the goal of being able to shoot down tactical targets such as surface-to-air missiles and rockets.

"DARPA has historically been the focal point for innovative high-energy laser developments," said HELLADS Program Manager Don Woodbury. "While most of the past efforts were focused on developing large, megawatt-class lasers to defend against ICBMs, HELLADS is focused on the tactical needs of the services, including the protection of aircraft against surface-to-air missiles, protecting ground-based forces against rockets, artillery, and mortars, and protecting ships against anti-ship missiles. To be relevant to tactical systems, a compact and efficient laser weapon is necessary."

With a weight goal of less than 5 kg/kW, and a volume goal of less than 3 cubic meters, HELLADS will enable high-energy laser weapons to be integrated onto tactical aircraft and will significantly increase engagement ranges compared to ground-based systems of equivalent power.

HELLADS is focused on development and weaponization of a solid-state laser, instead of using chemicals to create the laser energy.

"The HELLADS laser is designed to run off of the electrical power of the host platform, with the potential for an unlimited run time and an unlimited magazine depth," explained Woodbury. "The only consumables with HELLADS are power and air."

The HELLADS program has completed the design and demonstration of a revolutionary sub-scale high-energy laser that supports the goal of a lightweight and compact high-energy laser weapon system. Currently the program is focused on developing "unit cell laser modules" that are to be combined into a single laser resonator to produce a 150-kW laser. Competing unit cell laser modules with integrated power and thermal management have been designed and will be fabricated and demonstrated with a total output power of 50-75 kW.

Based on the results of the unit cell laser module demonstrations, additional laser modules will be fabricated to produce the 150-kW laser. In collaboration with the Air Force Research Laboratory's Directed Energy Laboratory, the 150-kW laser will then be integrated with other subsystems to produce a laser weapon system demonstrator.

Test firing against a pair of SA-10 or similar surface-to-air missiles and other targets is scheduled for late 2010 at North Oscura Peak, an Air Force Research Laboratory test site that is part of the U.S. Army's White Sands Missile Range in New Mexico.

"A 150 kW laser weapon system with a total weight of 750 kg and a volume of 3 cubic meters can be integrated in a fighter, a bomber, command and control aircraft, and even in helicopters," said Woodbury. "HELLADS offers the potential to add the capabilities of a laser weapon system to a host platform while maintaining existing platform capabilities."

One of the great advantages of using a laser for both defensive and offensive operations is that it can significantly reduce the collateral damage typically caused by other weapons.

"The laser is a speed-of-light weapon that is ultra precise in terms of its ability to destroy individual targets to avoid collateral damage that would occur, for example, if you used a Small Diameter Bomb in an urban environment," said Woodbury. "With the laser we can keep the beam tight and on target. It doesn't matter if the missile is on the ground or in flight, or how fast the target is moving."

There are two levels of challenges that DARPA engineers are facing with HELLADS, according to Woodbury. The first and easier challenge is coming up with a high-energy laser with the necessary performance in a laboratory environment to accomplish its mission of shooting down missiles in a real-world environment.

"More challenging is the need to develop a laser that includes all the necessary characteristics for weaponization: size, power, beam quality, reduced complexity, and sufficient robustness to withstand the rigors of an aircraft operating environment," he said. "Designing a laser that is compact, efficient, and capable of being utilized outside of a laboratory environment is a great challenge."

Doing so will give HELLADS both a defensive and offensive capability, and could create new roles for aircraft never before envisioned by military planners.

"HELLADS changes the way one thinks about using platforms," said Woodbury. "Imagine an aerodynamically efficient platform like a B-1 bomber that is not very stealthy or very fast being able to destroy a salvo of air-to-air missiles – and to be able to do so until the enemy runs out of missiles or the aircraft runs out of gas." Could this capability enable a B-1 to penetrate enemy air defenses and, like the F-117s over Baghdad in Desert Storm, fly in a manner that is best suited for the delivery of precision effects? Could such a system perform some of the missions envisioned for future hypersonic or stealthy platforms? Could moderate levels of stealth and speed, combined with self-defense, provide a more affordable path for future platforms? Stay tuned.

Another DARPA effort for high-energy airborne lasers, the Aero-Adaptive/Aero-Optic Beam Control (ABC) program, uses an innovative turbulence control method in order to improve lethality in high-speed flight, particularly in the aft field of regard.

In order to achieve high off-boresight targeting capability, current optical turret designs protrude into the flow. This causes severe aero-optic distortions in the aft field of regard due to turbulence in the wake and the unsteady shock movement over the aperture. These distortions decrease the power flux on target and limit the directed energy system to targets in the forward hemisphere.

The ABC program will optimize flow control strategies for pointing angles in the aft field of regard. The program is exploring the ability of the flow control system to be synchronized with the adaptive optics. ABC focuses initially on wind tunnel testing to prove the feasibility of steady and periodic flow control techniques to reduce or regularize the large-scale turbulent structures surrounding an optical turret. These tests will culminate in a full-scale hardware-in-the-loop demonstration with an adaptive optics system.

Following successful wind tunnel demonstrations, a preliminary design of a flight test turret incorporating flow control on the turret will be undertaken. Flight test of the selected flow control system may also be conducted, simulating an operational system in a representative environment.