DARPA's Space History

Dr. Owen Brown, DARPA Tactical Technology Office
LtCol Fred Kennedy, DARPA Tactical Technology Office
Dr. Wade Pulliam, DARPA Tactical Technology Office

Five decades ago, it was just a simple "beep-beep" that surprised the free world and especially the United States. That beeping came from a crude transmitter inside a 84 kg satellite circling the globe in low earth orbit. The radio signal, first heard from the sky on October 4, 1957 from Sputnik I, did not just signal the beginning of the space race between the United States and the Soviet Union, but also began a series of events that brought about the formation of DARPA, or the Defense Advanced Research Projects Agency. This agency, ARPA as it was know at its beginning[1], is best known for its part in developing the internet and stealth technology, but it has a proud history in space technology, playing a key part in the development and demonstration of the space infrastructure, both military and civilian, that we know today. Although the United States was beaten to the punch in launching the first artificial satellite, ARPA had a hand in first demonstrating many of the practical applications of satellite technology now prevalent, including: communications, weather forecasting, early warning, reconnaissance, and geo-location. Additionally, ARPA provided the early leadership and funding for the launch systems that would later be used by NASA to win the space race by landing a man on the moon.

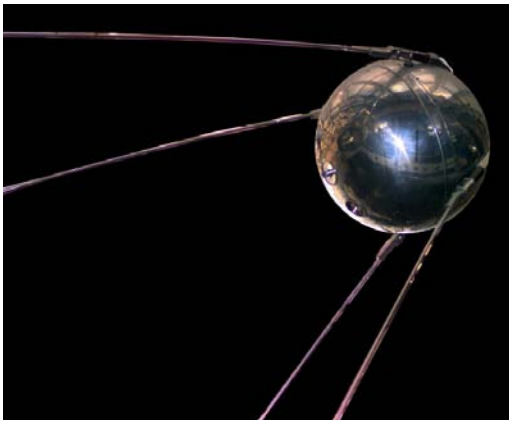
Although DARPA has expanded its mission to one of preventing technological surprise in domains other than space, it has remained active in space technology development and demonstration to this day. In this short chapter, the history of DARPA's beginnings will be told. DARPA's space programs over the last 50 years ago will be summarized. As stated, many of these space programs were precursors to disruptive space capabilities familiar to us all.

[1] DARPA was known as ARPA, the Advanced Research Projects Agency, from its founding in 1958 until March of 1972 when its name was official changed to DARPA with the addition of Defense. The agency's name reverted to ARPA between 1993 and 1996, at which time it again became known as DARPA. This chapter will use the name of the agency correct for the timeframe of the events being described.

The Launch Heard Around the World

"The Defense establishment must therefore plan for a better integration of its defense resources, particularly with respect to the newer weapons now building and under development. These obviously require full coordination in their development, production, and use. Good organization can help assure this coordination. In recognition of the need for single control in some of out more advanced development projects, the Secretary of Defense has already decided to concentrate into one organization all the anti-missile and satellite technology undertaken within the Department of Defense" – President Dwight Eisenhower, 1958 State of the Union Address

The launch of Sputnik I in October of 1957 should not have been a complete shock to the United States, or the West as a whole, but once the small satellite was placed into orbit, the sense of surprise was undeniable. The Soviets successfully tested an ICBM in the summer of 1957 (although its claims were doubted in some circles) and had been announcing for months that they planned to launch an artificial satellite. In fact the Deputy Director of the CIA, Herbert Scoville, stated in an open meeting on October 4th, only hours before the actual launch, that the "Soviets could launch a satellite this month, this week, or even today"[2]. The military threat was clear; soon the Soviets would have the capability to deliver nuclear weapons by missile to the continental US using the R-7 launch vehicle that had orbited Sputnik. However, what may have been worse was the blow the launch had to the American psyche. The belief in "American ingenuity" and the technological and educational superiority of the West was put to the test.



[2] York, Herbert, "Making Weapons, Talking Peace", Basic Books, 1987, p. 101

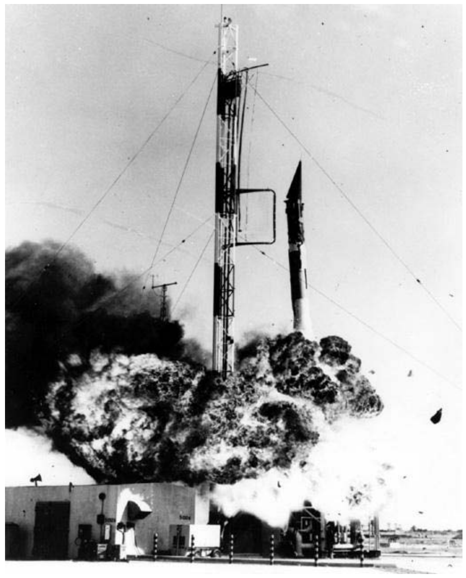
Sputnik 1. The Soviet launch of the world's first artificial satellite on October 4, 1957 provided the impetus for many changes in scientific, educational, and military policy in the United States, including the formation of the Advanced Research Projects Agency (ARPA).
(downloaded from http://nssdc.gsfc.nasa.gov/planetary/image/sputnik_asm.jpg)

Publically, Eisenhower expressed confidence that the US program was not that far behind. Privately, Eisenhower placed part of the blame for America's lagging space program on inter-service rivalries. Each service was pursuing a separate space program, which risked a lack of focused effort and a potential waste of resources. Just in the area of rockets, each service was developing its own system; the Army's Jupiter-C, the Air Force's Atlas, and the Navy's Polaris. Additionally, each service had satellite programs that it was pursuing. In short, each service was in effect ignoring some of its established military responsibilities by funding programs in the area of space in order to capture the new mission.

When Sputnik I was quickly followed in November by Sputnik II, a 500 kg satellite, the public and congressional apprehension became fervor, as it now became even clearer that the Soviets had the capability to deliver nuclear weapons by ballistic missile, which further created consternation within the Eisenhower administration.

This concern was further heightened by the launch pad explosion of the first US satellite launch attempt, Vanguard[3], on December 6th. Branded Flopnik by the press, the failure of Vanguard and the success of the Sputnik launches seemed to indicate that not only were the Soviets ahead, but that the US might not be able to catch up. The political pressure on the administration, especially from Senator Lyndon Johnson, became overwhelming. Over the next year, large changes in public policy were enacted to respond to the perceived problems: the teaching of science and mathematics was promoted by the National Defense Education Act and the job of sorting out the military's space program was given to a newly created organization, ARPA.

[3] The decision to proceed with the Naval Research Lab Vanguard program in 1955 resulted in the cancelation of a satellite launch by the Army Ballistic Missile Agency (ABMA), under the direction of Wernher von Braun; a system that in retrospect had a much higher probability of success given its direct lineage from the German V-2 program. In fact it was the proposed Jupiter-C rocket that was ultimately used to place the first US satellite into orbit, Explorer 1. Hughes, K., "Pioneering Efforts in Space", US Army Missile Command Historical Office, 1990



Vanguard 1a. The failure on December 6, 1957 of the Vanguard launch by the US Navy, what became known in the press as Flopnik, created more concern within the United States that the nation was behind in the space race.
(downloaded from http://exploration.grc.nasa.gov/education/rocket/gallery/history/vanbloom.jpg)

The President announced the new agency January 9th, 1958 in his State of the Union address and it was made official on February 7th when Secretary of Defense Neil McElroy issued DOD Directive 5105.15 formally establishing ARPA and gave it the 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." The immediate effect of this directive was the transfer of all military space projects to ARPA.

Explorer

It was not that the United States didn't have a program to launch a satellite. As part of its commitments to the worldwide cooperative scientific program, called the International Geophysical Year (IGY), the US had decided in 1955 to pursue a satellite launch. Unlike the Soviets, the US was pursuing separate tracks for its rocket development: a military rocket program to develop ICBMs and the Vanguard program to develop a launch system for the IGY satellite experiment[4]. The failure of the first Vanguard launch provided an opportunity for

[4] The US decided to pursue separate tracks for its launch systems for larger national security reasons. During this time the US was developing its reconnaissance satellites, but freedom of space overflight was not an established principle. It was hoped that a scientific payload tied to the IYG using a non-ICBM launch system could establish the precedent that overflight of a nation in

Wernher von Braun, and his team at the Army Ballistic Missile Agency (ABMA), to take the shot that they were denied in 1955, when the decision was made to proceed with the Vanguard program, based on the Viking missile.[5] Although this decision denied the US its shot to be first into space, the AMBA team was a ready back up and was quickly ordered to move ahead with a launch to attempt an orbit of a Jet Propulsion Lab built satellite, Explorer 1.

On January 31st, 1958, Explorer 1 was placed into orbit – officially entering the United States into the space age. From one point of view, the launch of the 14 kg satellite did not even come close to demonstrating the heavy-lift capability that the Soviets launch systems did with Sputnik II. However, what was often overlooked was that instead of the simple beeping of Sputnik 1, Explorer 1 carried a 8 kg scientific payload design by James Van Allen of Iowa State University, which discovered the existence of a belt of charged particles trapped in the earth's magnetic field. The discovery of the Van Allen belts was not only the most important outcome of the International Geophysical Year, it also clearly demonstrated the lead that the United States held in electronics and manufacturing technologies. Although the immediate military implication of being able to loft larger warheads understandably centered all the attention on the throw-weight lead of the Soviet systems, once the United States closed that gap, its lead in other technology areas allowed it to quickly demonstrate and take advantage of space systems to a much higher degree than the Soviets.

ARPA Demonstrates the Capabilities of Satellites

Provided with the impetus of presidential support and the feeling of national emergency, ARPA quickly began to sort out the United States space efforts and establish direction to what had been disjointed or overly ambitious efforts of the military services. The ideas and capabilities for many various space systems had been floated before often with proposals ready to be acted upon. However, these concepts had often languished without any focus or were wasting critical resources through duplication across the military services. ARPA spent the first seven months of its existence, during which it had decision making authority over the complete US space program (before the formation of NASA), sorting through these proposals and over-

---

orbit did not violate national airspace and that precedent could subsequently be used by the reconnaissance satellites. Ironically, the Soviets themselves provided that precedence with Sputnik. (Day, Logsdon, Latell, *Eye in the Sky: The Story of the CORONA Spy Satellites*, Smithsonian Institution Press, p. 120-125)

[5] Hughes, K., "Pioneering Efforts in Space", US Army Missile Command Historical Office, 1990

lapping efforts to impose order to the overall space program and funding to those space concepts which might have the greatest military utility. Yet in just these short few months, ARPA set the United States not only on a path toward winning of the space race, but also the first demonstrations of many of the space capability that are well known today.

SCORE – The world's first communication satellite

"This is the President of the United States speaking. Through the marvels of scientific advance, my voice is coming to you from a satellite traveling in outer space. My message is a simple one: Through this unique means l convey to you and all mankind, America's wish for peace on earth and good will toward men everywhere." - President Dwight Eisenhower, December 19, 1958

This Presidential message was one of the first examples of new space capability that ARPA was demonstrating during the first few years of its existence. SCORE, or Signal Communications Orbit Relay Equipment, was the world's first communication satellite. As with many of ARPA's early efforts in space, the first proposals for what would become SCORE had been pursued by the Signal Research and Development Laboratory (SRDL) at Fort Monmouth since 1955[6]. This proposal was picked up in July 1958 soon after the creation of ARPA.

In what would become a model for the agency of quick demonstrations of military capability, SRDL was given *60 days* to assemble a demonstration communication satellite to be placed in low earth orbit on top of an Air Force Atlas ICBM. The objectives of the SCORE program were two fold: primarily, that the Atlas launch system could place a payload in orbit[7], and secondarily, that a communication repeater[8] installed on-board could be used to transmit messages worldwide. Because the Atlas could only reach low earth orbit and only a limited number of ground stations existed, the SCORE system did not operate like the "bent-pipe" geostationary communication satellites of today. Instead the SRDL payload included both a real-time communication repeater for some over the horizon relaying of messages and a store and forward system that allowed the demonstration of worldwide message delivery through

[6] Theoretical studies had been in the open literature from as early as 1952, notwithstanding even early suggestions in science fiction. Brown, The Army Communicator, Winter 1982, p. 60

[7] The early Atlas systems were an unusual configuration in which 2 of the 3 engines would be jettisoned, but a majority of the structure and fuel tanks would remain.

[8] Martin, D., Anderson, P., Bartamain, L., "The History of Satellites", Communication Satellites, The Aerospace Press, 5th Ed.

uploading of coded messages onto an on-board tape recorder and download by the receiving station when the satellite came into view. It was this tape-delay system that was used to relay President Eisenhower's message to ground stations across the globe. Although the project schedule soon slipped to 90 days due to delays in the Atlas production, the full system was ready by December, 1958, less than 5 months from project go-ahead.

The launch was a complete success. The Atlas placed 4000 kg into low earth orbit (the SCORE payload weighing 68 kg), clearly demonstrating the capabilities of the Air Force Atlas ICBM to place payloads into orbit[9]. The communication payload also operated successfully, transmitting voice and teletype messages in both real-time and tape delayed mode 78 times during its 12 day lifetime. Through this experiment, the US had demonstrated more capability with launch systems and payload capability than the USSR had, passing the Russians just 14 months after the space race began.

As with the other projects it began, ARPA took an agile management role in the SCORE system development, with the Air Force being handed the responsibility for the Atlas, built by General Dynamics, and SRDL for the payload, built by RCA. This approach of maintaining low overhead was, and still is, a vital part of the success of the agency, especially during the early years when so many space systems were being developed and demonstrated. In what would become standard procedure, the agency concentrated on developing and fostering innovative concepts, as well as making key project funding decisions, while leaving the burden of facility and workforce maintenance, system development and production, and operations to industry, research labs, and the military services. At first this decision was made mostly for the bureaucratic reason of limiting the objections of the services at having their space programs transferred to ARPA[10]. In the long run, however, it has served the agency well in keeping it nimble, capable of changing directions quickly and able to manage many efforts rather than just a few.

[9] The Atlas had previously been demonstrated as an ICBM in December, 1957
[10] York, p. 139

CORONA – The world's first reconnaissance satellite

"And if nothing else had come out of it [the space program] except the knowledge that we've gained from space photography, it would be worth 10 times what the whole program has cost. Because tonight we know how many missiles the enemy has and, it turns out, our guesses were way off. We were doing things we didn't need to do. We were building things we didn't need to build. We were harboring fears we didn't need to harbor. Because of satellites, I know how many missiles the enemy has." – President Lyndon Johnson, 1967

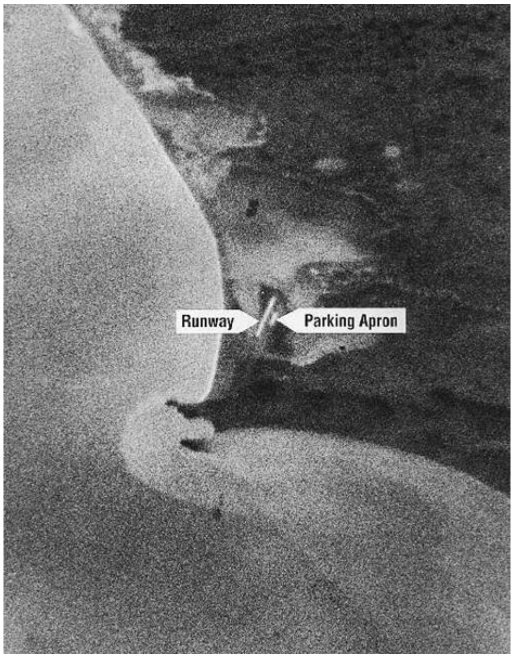
No other space effort, either within or outside of ARPA's history can say to have been more important to the national needs of the time than CORONA. During a time when the discussion in US national security circles was of the "bomber gap" and the "missile gap", it was unclear where the US stood vis-à-vis the Soviet Union in the early stages of the Cold War and the fear was that the US was falling behind both militarily and scientifically. Even though it was clear that the US required a strategic reconnaissance system to gather necessary intelligence from the USSR, the correct system to pursue was not necessarily clear. During the late 1950's, the United States operated the U-2 over Soviet airspace in an effort to gather that information. However, even as it was being built, Kelly Johnson (the U-2's designer) knew that the U-2 was a stopgap measure, realizing that before long the Soviets would find a way to bring the aircraft down. Once the SA-2 was fielded in operationally significant numbers, the U-2's days as a strategic reconnaissance asset against the Soviet Union were numbered, which was demonstrated clearly by the downing of Gary Powers.

During this time period the US was considering diversifying its strategic intelligence capability by developing reconnaissance satellites. This concept was first proposed in the Project Feed Back by RAND in 1954 and by 1956 the Air Force initiated a program dubbed WS-117L, also known as Janus. The system was centered on a complex photography system; calling for film to be processed onboard and then the images scanned and beamed down to ground stations. Although the system has positive attributes such as quick delivery of intelligence, a simple concept for data recovery, and a long mission time (as much as a year), these features led to stressing requirements on other components and on the system design itself.

When ARPA was created in 1958, the Janus program was stuck in technology development delays, mostly caused by its overly ambitious requirements. Once the Janus program was transferred to ARPA management, it became three separate efforts: DISCOVERER, SENTRY, and MIDAS. It was hoped that by splitting and therefore focusing the effort, each would be able to more quickly make progress than they had as a unitary program.

The SENTRY Project, later called SAMOS, would continue to develop photographic reconnaissance systems utilizing radio-transmissions, and was immediately turned back over to the Air Force to run. In later years the developments of this program lead to the series of satellites that provide strategic reconnaissance for the United States today. MIDAS would develop infrared, wide-area missile warning satellites, an early precursor of the current DSP satellites.

The third program, DISCOVERER, would develop a reconnaissance satellite based on a film return system - what would become CORONA. The concept called for the mating of a Thor booster with an Agena second stage to put a satellite containing a small-grain film camera system in a polar orbit. After just 17-18 orbits, stabilized through the 3-axis orientation rocket system on the Agena, the film, protected in a re-entry pod, would be ejected from the satellite, re-enter the atmosphere, be decelerated and then recovered in mid-air by specially equipped aircraft. This system concept, although complex from an operational point of view, was judged more technologically feasible at the time than that of SENTRY. Given the high priority the strategic situation imposed on satellite reconnaissance, the CORONA effort was begun and initially funded by ARPA and then management of its development was handed over to the CIA (final operational control of the program was transferred to the Air Force, which then formed the National Reconnaissance Office around it).



CORONA. The first picture taken over the Soviet landmass by the world's first reconnaissance satellite, DISCOVERER XIV. The CORONA program was one of ARPA's first efforts in space and produced in 30 months a vital asset for the United States, filling in the gap in strategic intelligence left by the downing of Gary Power's U-2.
(Downloaded at http://www.nasm.si.edu/exhibitions/GAL114/SpaceRace/sec400/sec420.htm)

Although not successful until its 14th attempt[11], just 30 months after program inception (and 18 months after the first launch), the CORONA program was a resounding success. DISCOVERER XIV returned over 3600 ft of film, covering 1.5 million square miles of the USSR (approximately 17% of the Soviet landmass) – more than had been collected over the Soviet Union during the entire U-2 program[12]. This first mission dramatically changed the strategic calculus for Washington, showing that instead of the Soviets having scores of ICBMs, they had approximately six[13], meaning that if there was a missile gap, in was in favor of the US. This information, and that which followed in subsequent missions, allowed the US to be more forceful in confrontations with Moscow and more circumspect in its own weapons programs, saving valuable resources. CORONA would remain the backbone of US strategic photographic intelligence into the 1970's when it was finally superseded by satellites that could relay imagery electronically to the ground.

---

[11] August 19, 1960 - just 110 days after the loss of Gary Power's U-2 marking the last U-2 flight over the USSR and coincidentally the day he was convicted of espionage by the Soviet Union
[12] Taubman, *Secret Empire: Eisenhower, the CIA, and Hidden Story of America's Space Espionage*, Simon &Schuster,, p. 322
[13] Day, Logsdon, Latell, *Eye in the Sky: The Story of the CORONA Spy Satellites*, Smithsonian Institution Press, p. 25

TIROS – The world's first weather satellite

"The satellite that will turn its attention downward holds great promise for meteorology and the eventual improvement in weather forecasting. Present weather stations on land and sea can keep only about 10 percent of the atmosphere under surveillance. Two or three weather satellites could include a cloud inventory of the whole globe every few hours. From this inventory meteorologists believe they could spot large storms (including hurricanes) in their early stages and chart their direction of movement with much more accuracy. Other instruments on the satellites will measure for the first time how much solar energy is falling on the earth's atmosphere and how much is refracted and reflected back into space by clouds, oceans, the continents, and by the great polar ice fields." - "Introductions to Outer Space", President's Science Advisory Committee (PSAC), March 1958

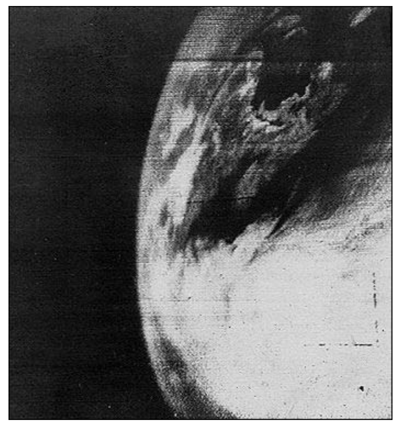
Although incredibly successful, the CORONA system had one major drawback; the film return design meant that each mission had a limited lifetime, approximately 27 hours, in which the timing of the photography was preprogrammed so as to maximize the intelligence captured over the Soviet Union. A launch on the wrong day over Russia would provide just very expensive pictures of the tops of clouds. Out of this limitation grew an urgent requirement for a meteorological satellite system to assist in the operation of optical reconnaissance satellites; a need which was filled by the TIROS (Television Infrared Observation Satellite) program.[14]

The desire for a weather satellite actually dated back to the 1940's and had been part of the IGY plans[15]. But it was in the shake out of the Air Force Janus program where TIROS was born. The technical means to take television pictures of necessary resolution for strategic reconnaissance and to transmit them back to earth was still years out when ARPA was handed the responsibility for the Janus program at its creation. ARPA staff realized that although the available television camera technology of 1958 provided insufficient resolution for targeting and surveillance missions within the allowed weight limit, it was completely adequate for the

---

[14] Reed, S., Van Atta, R., Deitchman, S., "DARPA Technical Accomplishments: An Historical Review of Selected DARPA Projects", Institute for Defense Analyses Paper, 1990, p. 2-1
[15] Ibid, p. 2-2 – 2-3

meteorological requirement. Therefore, in July 1958, ARPA redirected RCA[16], which had been working on the television surveillance system for Janus, to begin the development and construction of a demonstration weather satellite, TIROS I. The satellite was a spin-stabilized, pill-box design (see photograph) that included two television cameras-one low and one high resolution (550 lines per frame)-and was powered by 9,200 solar cells[17] – the first major use of solar cells to power a satellite. By the time the TIROS project was handed to NASA in April 1959, the plans and funding for the payload construction, launch, and data analysis were already in place.



TIROS A (left). The first weather satellite program, TIROS, launched by NASA in 1960 (first picture on right from April 1, 1960), was started by ARPA. Improved weather predictions made capable by satellite data have vastly improved military planning and saved countless civilian lives through advanced warning of large storms.
(downloaded from http://history.nasa.gov/SP-168/p202a.jpg and http://earthobservatory.nasa.gov/Library/RemoteSensingAtmosphere/Images/first_tiros.jpg)

Launched a year later on April 1, 1960 on top of an Air Force Thor booster, TIROS I was an instant success. During its 78 day lifetime, it provided 19,389 pictures of cloud cover that were considered valuable (out of nearly 23,000 taken) and also some pictures of sea ice useful in ice reconnaissance[18]. Some of these first pictures showed features that were identified as large storms, immediately demonstrating the capability to assist in weather forecasting. While worldwide data without interruptions was not achieved until 1966, TIROS was immediately considered semi-operational[19]. However, the legacy of the TIROS program is much larger than improved operational planning for reconnaissance satellites; it ushered in a new age of weather

[16] Management of RCA's contract was handed to the Army Signal Corps R&D lab
[17] Reed, p. 2-5
[18] Widger, W., "Meteorological Satellites", Holt, 1966, p. 136
[19] Ashby, J., "A Preliminary History of the Evolution of the TIROS Weather Satellite System", NASA, 1964, p. 10

forecasting, both civilian and military. Not only was day-to-day forecasting improved, the ability to track major storms over the ocean was revolutionized, providing coastal communities and ships at sea the warning that they needed to save countless lives. Beside the development of the internet (and maybe satellite communications), few other ARPA programs have had such a profound impact on the entire world.

TRANSIT – The world's first navigation satellite

"[T]he discovery of the longitude, the perpetual motion, the universal medicine, and many other great inventions brought to the utmost perfection." - Doctor Lemuel Gulliver when asked to imagine what he might be able to see if he were immortal.

Used in *Gulliver's Travels* as synonymous with attempting the impossible, accurately locating position on the earth, especially on the open sea, has been an age old problem. The inaccuracies in indirect method of determining position, typically one or another version of dead-reckoning guidance, led ships of Swift's time to miss their resupply ports, take inefficient routes, and cluster around known shipping lanes, making easy prey for piracy. In hopes of solving the problem, the British Parliament in 1714 passed the Longitude Act, which offered support and incentive awards to inventors who could devise a system for accurately determining longitude for the Royal Navy (latitude was determined through the use of a sextant). To administer these awards, the act set up the Board of Longitude, perhaps the world's first research and development organization[20]. Through support of the TRANSIT program, the world's first navigation satellite, ARPA was able to bring to final conclusion what that first R&D organization could not, accurate geo-location on the open sea.

As with the TIROS satellite system, TRANSIT was born out of requirements of the strategic struggle between the US and USSR, but became a dual military-civilian asset. It would become the forerunner of the modern GPS constellation. In this case, the requirement was to provide accurate position data (within 0.1 nm) to Polaris-armed submarines during their patrols

[20] Sobel, Dava, "A Brief History of Navigation," JPL Technical Digest, Vol 19, no. 1, 1998. Although disbursing more than ₤100,000, the prize was never fully paid off. The problem had been adequately solved for finding locations the size of ports by John Harrison who developed a more accurate, pendulum-free timepieces which could be used to calculated longitude given the calendar date

so that launch trajectories could be quickly calculated day or night with enough precision to hit their targets.[21] With the accuracy that TRANSIT facilitated, the ballistic submarine leg of the US nuclear triad could with confidence hit the targets assigned to it. In a destabilized strategic environment underlined by the potential of a knock-out Soviet first strike, the acknowledged capability of the nearly invulnerable submarine force to hit targets through the Soviet Union provided all the deterrence the United States would need – clearly demonstrating the importance of the TRANSIT program among those programs begun in ARPA's early years. But besides being a critical part of the US strategic system, TRANSIT provided position data to both military and civilian ships, oil rigs at seas and even land surveying, including those of the Defense Mapping Agency (now part of the National Geospatial Agency).

TRANSIT Satellite. The ARPA TRANSIT program was the first operational satellite positioning system which remained in operation until 1996 when the current GPS constellation became operational. Beside the general improvement in geo-location for military units, the TRANSIT satellite system was fundamental to the accuracy of the submarine-launched POLARIS missiles, and therefore a vital component in the United States' nuclear deterrent during the Cold War.
(downloaded from http://www.nasm.si.edu/exhibitions/gps/transit.gif)

Interestingly, the idea for TRANSIT was another unintended consequence of the Sputnik I and its incessant beeping. Researchers at the Johns Hopkins Applied Physics Lab (which was part of the Navy's system of research labs and was involved in the Polaris program) became fascinated with the Sputnik launch, as had most of the world. Their fascination led to efforts to determine its orbit from the Doppler shifts of the beeping. Once successful, it didn't take long for them to realize that the problem could be inverted – that a location on earth could be calculated by knowledge of the orbit of a satellite, which could be updated from ground tracking stations once the satellite was in orbit, and the Doppler shift of a signal from that satellite,

[21] Danchik, Robert J, "An Overview of Transit Development", *John Hopkins APL Technical Digest*, Volume 19, Number 1, 1998.

measured with a ground receiver/computer system[22]. Within just months of the Sputnik launch, APL had been able to fully develop the concept for the proposed satellite navigation system. The benefits of this solution, especially for submarines, as compared to other forms of navigation were overwhelming. The polar orbits of the satellites allowed worldwide coverage of the system, Since the measurements of angles or directions are not required, simple omni-directional antennas can be used (very useful on a pitching ship and with a submarine that only has to expose a small antenna at appropriate times). As the method uses radio frequencies, the solution is all-weather. Now a submarine in the open ocean could in any conditions and with minimal exposure, determine its location worldwide within 200 m. Almost by accident, APL had found the solution to the problem of determining missile launch coordinates on a moving platform.

The TRANSIT program proved to be an example of the benefit of having an R&D organization like ARPA outside of the services; a benefit that the DoD has reaped time and time again since the founding of ARPA. In the TRANSIT example, because the DoD responsibility for space programs lay outside of the Navy in 1958, APL brought the proposal to ARPA, where in October 1958 it was quickly approved and funded for all the pieces of a demonstration system including the construction of a demonstration satellite, tracking/orbit update stations, launch systems, and the development of ground navigation equipment/receivers.

The first successful TRANSIT launch was in April 1960 (TRANSIT 1B), just 18 months after project approval and demonstrated the feasibility of satellite navigation. Just as other early ARPA programs, TRANSIT had secondary demonstration goals. The Able-Star second stage demonstrated for the first time an engine restart in space. Also, TRANSIT 1B tested the first magnetic torquer devise used for satellite attitude control and a solar attitude detector. Future versions of TRANSIT demonstrated for the first time gravity-gradient stabilization, allowing a directional antenna for transmitting its signal, greatly decreasing on-board power requirements. Another side benefit of the TRANSIT program was greatly improved scientific knowledge of the earth's gravitational field through the large data set provided by the TRANSIT satellites and tracking stations. This geodesy knowledge was the fundamental limiting factor to position calculations as slight changes in the earth's gravitational field would slightly alter the satellites orbit. By 1965, the gravity model had become sufficiently accurate to reduce the positional

[22] a different operating principle than the current GPS navigation system

accuracy of TRANSIT to less than 400 m, the requirement set for POLARIS. [23] By 1968, the TRANSIT system was declared fully operation by the Navy and had already begun to be used for civilian applications. The system remained in active service until 1996 when the current GPS system became fully operational.

VELA HOTEL

"Each of the Parties to this Treaty undertakes to prohibit, to prevent, and not to carry out any nuclear weapon test explosion, or any other nuclear explosion … in the atmosphere; beyond its limits, including outer space; or under water, including territorial waters or high seas" – Limited Test Ban Treaty of 1963

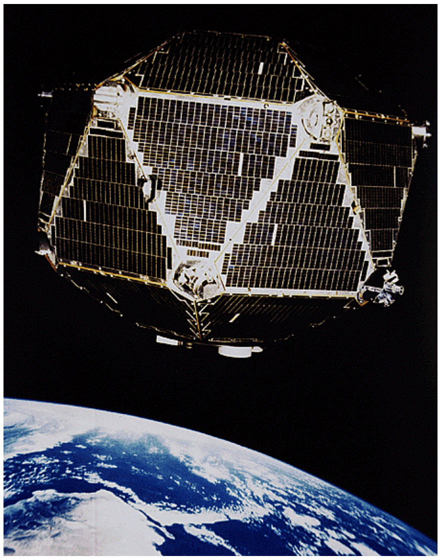
During the second ever very large thermonuclear test at Bikini Atoll in March of 1954, poor prediction of the fallout pattern from such a large explosion led to the unintentional exposure of hundreds of Marshall Island natives to high, but non-lethal, levels of radiation. The ironically named *Fortunate Dragon*, a Japanese fishing boat, was in the area and also received very high doses of radiation which proved to be fatal for its captain. This "Bravo" nuclear fallout accident focused international attention on nuclear testing and spurred President Eisenhower to consider proposing a nuclear test ban as a solution to the fallout issue and possible slow down the arms race.[24] By 1957, the issue had been given to the Presidential Science Advisory Committee (PSAC) to consider both the implications for a nuclear testing ban and methods in order to verify such a treaty. The latter effort was, in part[25], undertaken by the High Altitude Detection panel (the Panofsky panel) of PSAC, which recommended that a satellite system be employed to detect atmospheric or space nuclear tests as part of a verification system for a possible nuclear test ban treaty.

In a continuation of presidentially directed programs, Eisenhower assigned ARPA in the summer of 1959 the task of developing the technologies necessary for the detection of nuclear tests, what would become Project VELA (Vela means watchman in Spanish). This program would examine technologies for detection space and atmospheric tests by satellites (VELA

[23] Reed, p. 3-7
[24] York, p. 117
[25] Reed, 11-1. Separate panels were assigned to examine parts of the testing ban, such as underground (the Berkner Panel).

HOTEL) or by ground-based system (VELA SIERRA) and for underground test by large seismic arrays (VELA UNIFORM).

By September, ARPA had already planned for the required launchers for VELA HOTEL and had assigned Los Alamos and Sandia the responsibility for designing the satellite system and execution of the effort to the Air Force. The goal of the program was to develop a satellite system that would be able to detect a minimum 10 kiloton nuclear explosion taking place on the surface of the Earth from as far away as 160 million kilometers. By 1963, the first of the satellites were ready for launch, and just in time. In April, 1963 the UK, US, and USSR signed the Limited Test Ban Treaty (banning atmospheric and space testing of nuclear weapons), which went into effect on October 10 of that year. Just 7 days later, the first pair (of six) of VELA satellites was launched on top of an Altas-Agena rocket and placed in 115,000 km circular orbit, beyond the outer Van Allen belt and nearly a quarter of the way to the moon - higher than any military satellite had been placed before. Spaced 180 degrees apart from each other and at an altitude that could examine a complete hemisphere, this first pair quickly established a verification method for the new treaty. It is noteworthy that the second pair of VELA satellites detected the Chinese Lop Nor test in 1964, quickly demonstrating their capability and utility.[26]



VELA 5 Satellite. A Presidential directed effort, the ARPA VELA HOTEL satellites, part of the larger VELA program, provided the United States with the means to detect atmospheric and space nuclear detonations, a key verification capability in support of the Limited Test Ban Treaty.
(downloaded form http://imagine.gsfc.nasa.gov/Images/vela5b/vela5b_5sm.gif)

[26] Magnuson, S., "History of DARPA in Space", 50 Years of Bridging the Gap, 2008, p. 114

Under the ARPA program, 6 pairs of VELA satellites were eventually placed into orbit from 1963 through 1970. The first two pair included neutron and gamma ray detectors, designed by Los Alamos and Sandia to measure the characteristics of a nuclear explosion in space. As has been true of many ARPA programs throughout its history, science and equipment that has first been developed and tested for military purposes has the unintended consequence of vastly improving or creating a new area of science. In the case of the VELA HOTEL satellites, the gamma ray detectors that were developed to detect a nuclear test in space kick started the field of gamma ray astronomy, [27] key in the identification of supernovae and measurements of the early universe just after the Big Bang. On the third pair of spacecraft, launched in 1965, an optical instrument, called a bhangmeter, was added to provide a separate modality to identifying and verifying atmospheric tests. The bhangmeter, developed by Los Alamos for this purpose, measured the double flash signature that is characteristic of an atmospheric nuclear detonation. The utility of the bhangmeter in the third pair was limited by the satellite's spin stabilization. But by 1967, the fourth pair was gravity gradient stabilized (earth-oriented), which greatly improved their capability. The last two pair (1970) also included an electromagnetic pulse detector, even further increasing the data sets necessary to reduce false positives.[28]

The VELA program was completely transferred to the Air Force in 1970 after the launch of the last pair. Since July 1983, the GPS satellite network has carried the nuclear test detection equipment, including X-ray, bhangmeter, and EMP detectors, and in September 1984, the VELA satellites were shut down[29]. However, during the time that the VELA HOTEL satellites were operational, it is believed they did not miss a single nuclear event that they were in a position to observe, providing the verification capability necessary to support the Limited Test Ban Treaty.[30] Even more importantly, the known capability of the US to detect atmospheric nuclear tests, and through the VELA UNIFORM program underground tests, has been a disincentive to aspiring nuclear powers to attempt to test nuclear weapons in secrecy.

ARPA's Role in Launch Vehicle Development

[27] York, p. 220
[28] Reed, 11-6
[29] Reed, 11-7
[30] Argo, Harold, "Satellite Verification of Arms Control Agreements", *Arms Control Verification*, Pergamon Press, 1985, p. 292

In June 1958, the National Security Council invited ARPA to present its plans for developing launch vehicles. ARPA still had complete control over the US space program, but plans had already begun for a civilian agency, NASA, to take over the civilian aspect of the program. However, in that meeting, ARPA personnel set the ground work for the much of the launch architecture that would be used by NASA in reaching the moon and exploring the other planets – the use of clusters of engines for large launch vehicles (used in the Saturn series) and hydrogen-oxygen upper stages (Centaur)[31].

Centaur

"CENTAUR was "the" rocket by which NASA would conduct extensive earth orbit missions, lunar investigations, and planetary studies. Aside from military missions assigned to CENTAUR, which were to be considerable, NASA planned to launch one operational CENTAUR every month for a period extending well into the 1970's and beyond."[32]

The advantages of using LH_2/LOX as a rocket propellant had been recognized even by early rocket pioneers. However, working with and designing for cryogenic liquids could not be adequately overcome – producing, handling, and storing LH_2/LOX on the rocket proved to be too difficult for the engineering solutions of the time. During the early 1950's, though, the Atomic Energy Commission (AEC) had produced major advances in large-scale hydrogen generators and storage systems for its work in thermonuclear devices[33]. Additionally, during the mid-1950's, the Air Force, under contract to Lockheed, was pursuing a supersonic surveillance aircraft, SUNTAN, using LH_2 as its fuel. Pratt & Whitney was subcontracted to Lockheed as the propulsion lead, and successfully demonstrated that LH_2 could be used in a turbojet engine. The new found industrial capability to produce, handle and utilizing in a propulsive device re-energized the interest in LH_2/LOX as a solution to high-energy launch systems.

Before ARPA's creation, Convair had proposed to the Air Force that it develop a LH_2 upper stage for its Altas booster using the same thin-skinned, pressurized structure technology. Pratt & Whitney was also proposing using its experience in LH_2 propulsion to develop an upper

[31] Sloop, J., "Liquid Hydrogen as a Propulsion Fuel", NASA SP 4404, NASA historical series, 1978, p. 223
[32] "History of CENTAUR", NASA Lewis Research Center, undated, p. 2
[33] Reed, p. 4-2

stage. ARPA combined the proposals and in August, 1958 funded through the Air Force a joint Convair-Pratt effort to develop a LH_2/LOX upper stage for the Atlas booster, the Centaur.

Although the program was quickly transferred to NASA in October, 1958, the Centaur was already on a path for success. The program was the first to demonstrate the cooling of the nozzle with cryogenic fuel, the pumping and control of these fuels in zero gravity, and that thin-skinned metal structures could survive cryogenic embitterment. Also, as Centaur was intended as an upper stage, the program demonstrated engine restart and precision navigation, both necessary to achieve accurate orbits. All of these advances would be used in later launch systems, including the Saturn family and the Space Shuttle. The final version of Centaur has an operational proven Isp of over 444 sec (the Atlas booster, which uses RP-1 as fuel, achieves approximately 353 sec), underlining the vision of the ARPA judgment in LH_2/LOX technology and its teaming of Convair and Pratt. When mated to and Atlas booster, the Centaur is capable of placing 4 tons in LEO, 2 tons in GEO, and 1 ton to escape velocity[34]. As stated by a Glenn Research Center history, Centaur is simply "America's Workhorse in Space"[35].

The Atlas Centaur launch system. ARPA funded the development of the LH_2/LOX Centaur upper stage, as a high performance stage necessary to lift heavy payloads. Combined with the Atlas and Titan boosters, Centaur was the upper stage for launches of probes to Mercury, Venus, Mars, Jupiter, Saturn, Uranus, and Neptune. Centaur continues to serve as the Untied States' most powerful upper stage.

(downloaded from http://exploration.grc.nasa.gov/education/rocket/gallery/atlas/AtlasCentaur.jpg)

[34] Reed, 4-5

[35] http://www.nasa.gov/centers/glenn/about/history/centaur.html, downloaded 6/8/08

Saturn

"But why, some say, the moon? Why choose this as our goal? And they may well ask why climb the highest mountain? Why, 35 years ago, fly the Atlantic? Why does Rice play Texas? We choose to go to the moon. We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win." President John F. Kennedy, Rice University, 1962

Although President Kennedy provided the vision and drive behind the space program, and the moon shot in particular, to the nation as a whole, it was decisions and a time-saving suggestion that were made during that short period that ARPA controlled the US space program that jumpstarted the US booster program to be in a position to meet the challenge. Von Braun's group at ABMA had been working on a concept for a large booster since early 1957 – work that received a big push after the launch of Sputnik. Their concept, a major feature of ABMA's "National Integrated Missile and Space Development Program", proposed to speed the development of a large booster by ganging a cluster of existing missiles together and using a to-be-developed Rocketdyne E-1 engine burning RP-1/LOX. After being given the space mission at its formation in February 1958, ARPA pickup up on the concept and made a critical suggestion, recommending substituting eight existing Thor/Jupiter S-3D engines for the still-to-be-developed E-1, saving $60 million and two years in development time. With this change, ARPA provided funding of $92.5 million in August of 1958 to get the Juno V (soon to be changed to SATURN) project started[36]. ARPA continued its funding support through ground testing and the study of launch facilities – right up until the booster development was transferred to NASA.

[36] Reed, p. 5-2

Saturn 1b launching the Apollo 7 spacecraft. The Saturn family of launch systems was derived from the Juno (Jupiter-C) rocket developed by the Army Ballistic Missile Agency, funded by ARPA, and then transferred to NASA upon its creation.
(downloaded from http://exploration.grc.nasa.gov/education/rocket/gallery/atlas/Saturn1b.jpg)

The ARPA/ABMA first stage was successfully launched in October 1961 as part of the SATURN C-1 configuration. NASA used 10 SATURN C-1 launchers, which also included CENTAUR LH_2/LOX engines on the second and third stage, to test APOLLO procedures and equipment. The follow-on SATURN B-1, which used the same first stage and CENTAUR engines for the third, was used to test APOLLO systems and engines and demonstrate docking maneuvers right through 1966 when the SATURN V test flight began[37]. Although the final SATURN V configuration differed from these early models, it was the early support of ARPA for the cluster concept, the suggestion of using existing engines during early development, and the technology demonstration of LH_2/LOX engines in the CENTUAR program, that accelerated the US space program in its quest to beat President Kennedy's deadline and land a man on the moon by the end of the 1960's.

A New Mission

ARPA's control of the US civil space program was short-lived. Formed in February 1958 to accelerate the US space effort, it would be nearly completely out of the business in the civil effort by November 1959. It was clear even during the creation of ARPA that President Eisenhower and Senate Majority Leader Johnson desired for a civilian agency to pursue the

[37] Ibid, p. 5-6

space race. Although it took a little longer to pass the Space Act legislation (the authority already existed for the Secretary of Defense to create a new defense agency), by July 1958 NASA had been formed and by fall most of the civilian space effort had been transfer from ARPA to the new agency, including the Saturn and Centaur rocket development and the TIROS weather satellite program.

There was pressure on the military space side as well. The services had never fully accepted that a separate agency was needed for the military space program and noted that even at its peak ARPA had returned 80 percent of its programs back to the Air Force to manage[38]. Defense Secretary McElroy saw the issue the same way and on September 18, 1959 made the Air Force the executive agent for space, transferring the communication and early warning satellite programs to it.

Just 21 months after its creation as the central space agency for the United States, most the ARPA portfolio of program, and much of its budget, had been transferred to other entities. It would have to find a new mission, not the last time a major portion of the agency would be split off to form a new agency. It should be noted that many of the efforts that ARPA handled during its short period of control of the US space program were concepts that were already in existence – ARPA established some order and the funding necessary. However, in losing existing, established technology programs to the services ARPA found its mission – to push the beyond the capabilities of today and bridge the gap to the future.

DARPA in Space: the 80's and 90's

Although the years in the twentieth century following the early 1960's did not see frenetic space activity at DARPA, important programs and progress were non the less made. Significant DARPA space programs during the 1980's included the Global Low Orbiting Message Relay (GLOMR), manufactured by Defense Systems Inc, now a part of Orbital Sciences Corporation. GLOMR was a store and forward system designed to relay data from remote earth based sensors. A small, basketball sized 52 kg polyhedron, it was originally to be launched from Shuttle mission STS-51B, but a battery issue forced a delay. It was eventually launched on mission STS-61A on October 30, 1985 and released into orbit 2 days later (this was the second use of the Shuttle "Get-Away-Special",or GAS payload approach). It re-entered the earth's atmosphere 14 months later. A noteworthy bit of data: the price tag on the satellite was a mere $1M – ushering in the idea of a "cheapsat"[39]. GLOMR was a "back to the future" program

[38] Magnuson, p. 112
[39] Data from http://msl.jpl.nasa.gov/QuickLooks/glomrQL.html

of sorts for DARPA, as it was the second store and forward relay satellite launched – SCORE being the first.

Significantly DARPA contributed to the development of what today may be considered the workhorses of small satellite launch – the Taurus and Pegasus launch vehicles built by Orbital Sciences. Both vehicles relied on similar solid rocket boosters. Taurus, a ground launched system was designed to be rapidly integrated and erected at a simply launch site. Pegasus was inspired by the idea that an air-launched system would provide enhanced flexibility as it steered clear of range impediments (in addition its performance was enhanced because of increased efficiencies at higher altitudes).

DARPA's space activity in the 1980's and 1990's does appear at first glance to have been dwarfed by that which took place soon after Sputnik. But what is too overlooked is how other DARPA efforts in this time frame were *integrated* with newer space systems (with an ARPA/DARPA heritage) to provide unmatched advantage for the warfighter in the field during the last decade of the twentieth century. Satellite relayed UAV imagery, GPS guided munitions, and fully networked satellite communications for command and control are examples.

DARPA's Space Mission Enters the Next Millenium

"If the US is to avoid a 'space Pearl Harbor,' it needs to take seriously the possibility of an attack on US space systems ... The US is more dependent on space than any other nation. Yet the threat to the US and its allies in and from space does not command the attention it merits," Space Commission Report, 2001

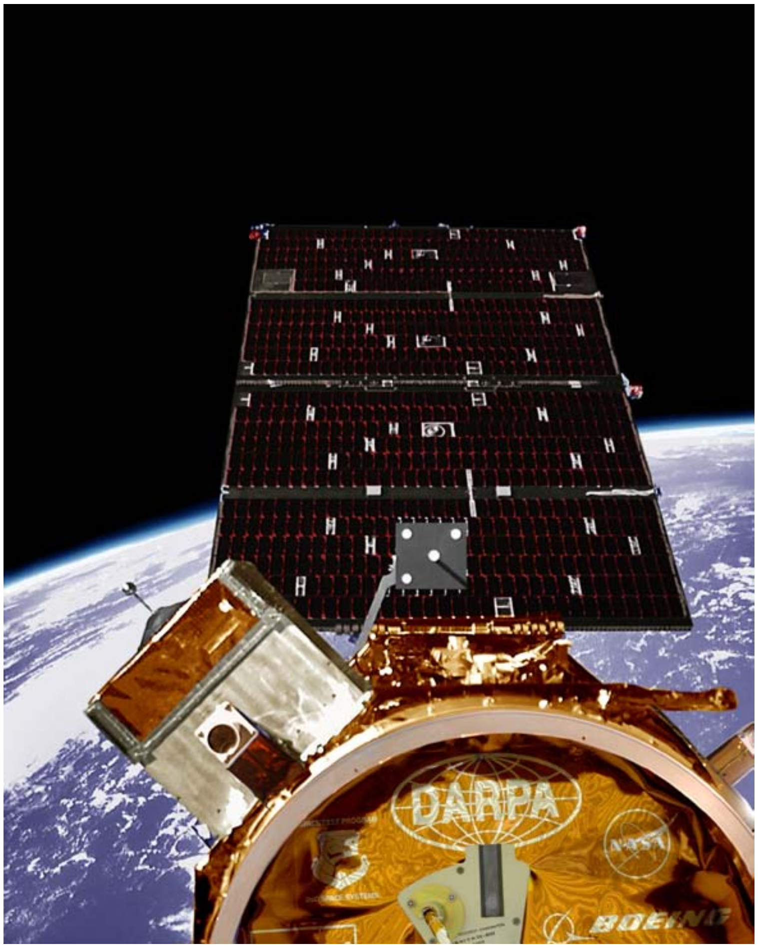
Thanks in part to the effort of early ARPA satellite and rocket pioneers, by 2000 space played a vital and enabling role in the nation's global military strategy and tactics, and just as importantly was paramount to the American economy and safety of its citizens. Global communications, GPS, accurate weather forecasting, and freedom through knowledge of the adversary were all now possible because of space technology. But, with this capability came vulnerability. Vulnerability not only in the form of catastrophic attack as made explicitly by the 2001 Space Commission, but vulnerability also in the form of technological surprise (like that of Sputnik) and the potential to fall behind in the technical supremacy needed to maintain a warfighting advantage. It was in this light that during his assignment to DARPA in mid-2001 that Dr. Anthony Tether was given the basic directive by then Secretary Donald Rumsfeld to get DARPA back into space (Rumsfeld of course headed the 2001 Space Commission which had published its findings early that year). Tether focused DARPA's space activities into major focus areas, among them being Space Protection, Space Situational Awareness, and Access and Infrastructure.

Two of the most dramatic programs that aimed to support the Access and Infrastructure domain are Falcon and Orbital Express. The Falcon program is "designed to vastly improve the U.S. capability to promptly reach orbit"[40]. This activity includes development of new hypersonic test vehicles that could bridge the gap between space and the atmosphere inhabited by aircraft. Falcon also focused efforts to develop new low-cost launch vehicles, including the SpaceX Falcon 1 launch vehicle. The initial first two tests were sponsored by DARPA, with the second launch successfully getting to space and providing important data for continued develop of this vehicle that could potentially open new markets to space users.

No other DARPA program in the recent past may have more profound impact on the future of space access and infrastructure than Orbital Express. Orbital Express was conceived in the late 1990s as a demonstration of autonomous robotic servicing and refueling of spacecraft. The Hubble repair missions conducted by Space Shuttle crews have demonstrated the undeniable value of satellite servicing. As in the case of Hubble, too often spacecraft that have required enormous resources to build and launch fail within weeks of placement on orbit. Likewise, as technologies rapidly evolve in the post-information age, the ability to replace outdated sensors and computers onboard otherwise healthy satellites can bring increased utility to their users. Orbital Express was created with these thoughts in mind, but with the knowledge that human spaceflight repair missions – although very valuable – are very costly as well. By creating an autonomous capability for repair, costs could be vastly reduced and mission turnaround time could be decreased. When considering Orbital Express, its developers evaluated historical space programs and concluded that a key life limiting factor for many satellites is its store of propellant, used to provide for maneuvering and station-keeping. The amount of propellant available is limited by launch vehicle and spacecraft constraints on mass and volume. By allowing a means to refuel on-orbit, satellites' operational lifetimes could be increased, or they could be allowed to maneuver more frequently. Other life limiting elements include onboard batteries and computers, which can degrade (in the case of the former) or become obsolescent (in the case of the latter).

[40] 2007 DARPA Strategic Plan

In 2000, the Boeing Company's Phantom Works was awarded a contract to develop the Orbital Express system. Phantom Works designed and built the autonomous servicer, ASTRO (Autonomous Space Transfer and Robotic Orbiter), while the client (servicee) spacecraft, NextSat was built by Ball Aerospace. ASTRO, which weighed in at 1000 kg (carrying propellant both for itself and NextSat), used two optical cameras, a laser rangefinder, a NASA-designed laser ranging and client pose determination system, and an infrared camera for rendezvous, proximity operations, and docking of NextSat. The smaller 225 kg (dry) NextSat was fitted only with targets and retro-reflectors to assist ASTRO's sensors. A special docking mechanism allowed reliable mating of the two spacecraft, even at off-nominal docking angles. A fluid transfer mechanism was developed to pump or pressure-feed hydrazine propellant from one vehicle to the other. A purpose-built robotic arm allowed for the berthing of NextSat and the removal and replacement of modular flight computers and batteries.



An in-orbit view of NextSat from ASTRO during DARPA's Orbital Express Mission.

Launch of the Orbital Express took place on 8 March 2007 from Cape Canaveral. Over the next 135 days, the mission conducted 14 refueling operations, demonstrated six battery transfers and a flight computer changeout, and performed seven discrete autonomous rendezvous and docking operations from separation distances of as much as 400 km. Each operation would begin with ASTRO and NextSat in the mated configuration. ASTRO would then fire its thrusters and retreat along a preset trajectory to a target separation distance, then return and dock.

With Orbital Express, DARPA offered a new way of thinking about the design and operation of future space systems: not only can serviceable satellites offer unmatched capabilities, they also provide decision makers and warfighters with the ability to change or modify these capabilities at any time in their lifecycle, as well as the ability to continue to perform the intended mission despite changes to the operating environment. These are the respective definitions of flexibility and robustness. Flexibility and robustness will be critical in a future filled with uncertain threats, uncertain technological development timeliness, uncertain budgets, and uncertain performance.

Closing Thoughts

It was a simple beep from Sputnik that surprised a nation and spurred the creation of a radically innovative agency called ARPA. Now DARPA, the legacy of the agency in space is incredible. The roots of vital communication, weather, sensing, and navigation spacecraft are found at DARPA. Today new roots are being planted that may yield yet again unparalleled space capabilities. The events of the future are difficult to predict. DARPA has no crystal ball. But DARPA will remain committed to preventing the United States from being surprised by the future. As in the past, DARPA in fact will continue to harness the genius of innovative people to create technologies that will change and indeed shape the future.