INNOVATIONS & INNOVATORS OF THE NATIONAL RECONNAISSANCE OFFICE

1961 - 2021

INNOVATIONS & INNOVATORS

OF THE NATIONAL RECONNAISSANCE OFFICE

1961 - 2021

CENTER FOR THE STUDY OF
NATIONAL RECONNAISSANCE

MAY 2023

CENTER FOR THE STUDY OF NATIONAL RECONNAISSANCE

The Center for the Study of National Reconnaissance (CSNR) is an independent National Reconnaissance Office (NRO) research body reporting to the Director/Business Plans and Operations Directorate, NRO. The CSNR's primary objective is to advance national reconnaissance and make available to NRO leadership the analytic framework and historical context to make effective policy and programmatic decisions. The CSNR accomplishes its mission by promoting the study, dialogue, and understanding of the discipline, practice, and history of national reconnaissance. The CSNR studies the past, analyzes the present, and searches for lessons for the future.

Contact Information: Phone, 703-227-9368; or e-mail, csnr@nro.mil

To Obtain Copies: Government personnel may obtain additional printed copies directly from CSNR. Selected CSNR publications are available on the Internet at the NRO web site.

Note: Images were pulled from NRO Archives.

Published by

NATIONAL RECONNAISSANCE OFFICE
Center for the Study of National Reconnaissance
14675 Lee Road
Chantilly, Virginia 20151-1715

CENTER FOR THE STUDY OF
NATIONAL RECONNAISSANCE

TABLE OF CONTENTS

INNOVATORS

FOUNDERS & PIONEERS

PEOPLE

NRO ORGANIZATIONS

GOVERNMENT PARTNERS

INDUSTRY PARTNERS

GROUND LOCATIONS

A NOTE TO THE READERS

The National Reconnaissance Office was established on 6 September 1961, uniting Central Intelligence Agency and Department of Defense reconnaissance satellite programs into a single agency. In the six decades that have passed, the NRO has accomplished innovations in many areas driven by a unique class of innovators. Some of the nation's best minds have labored to give the U.S. strategic and tactical advantages in protecting the nation from the vantage point of space. Additionally, the development of NRO systems also contributed to broader U.S. space programs and the advancement of commercial activities.

To commemorate the National Reconnaissance Office's 60th Anniversary in 2021, the staff of the NRO's Center for the Study of National Reconnaissance (CSNR) wrote a compilation of highlights celebrating various aspects of NRO history which we called "I&Is." The effort identified 60 "Innovations" developed by the NRO and 60 "Innovators" that have been involved with the NRO over the years — one specific example for each year of the NRO's existence and most of which are included in this publication.

The I&Is were released to the workforce periodically throughout the year, as the NRO celebrated its 60th anniversary. This publication is simply an effort to consolidate those highlights in one place for the ease of retrieval and education of all. The I&Is are short and general in nature, but each should contain enough information to inform the general reader, as well as to provide clues on where to find additional information for the advanced researcher.

We would like to note to the reader the parameters that defined this project. We are only highlighting unclassified accomplishments. This compilation was not intended to be a "Top 60" list, since many of the NRO's innovations are still highly classified and cannot yet be shared with the public. We also made no effort to "rank" the lists, since the innovations are in different areas — ranging from groundbreaking technological discoveries to innovative management practices to development of new ways of thinking — and any systemic criteria we chose to do so would be problematic. In addition, some of the innovations we included are still not fully declassified, and we can only consider the information that has been released, which in some cases is minimal.

The I&Is that we included are grouped into several different categories for organizational purposes only and for ease of the reader. Each report stands on its own, so while the reader will occasionally notice some duplication of information, it merely shows the interconnectivity of many of the NRO's programs and activities. No I&I is any more or less important than any other with no bias toward placement within the overall publication. Not all innovators or innovations were included because of classification and project limitations.

We hope that the reader will find this publication both compelling and informative. More information can always be found on the CSNR's "History and Studies" page of the NRO.gov website.

The CSNR Team

Chuck Glover, Christine Grannas, Annie Hakes, Courtney Homer, James Outzen
Alesia Rose, Ambika Sankaran, Wanda Smoot, Juliana Steiner, Mike Suk
Patrick Widlake, and Carol Willis

INNOVATIONS

NRO CULTURE

NRO CULTURE

Ultimately any organization that is highly innovative depends on developing, sustaining, and refreshing a culture that enables innovation. During its 60 years in existence, the National Reconnaissance Office (NRO) invented and nurtured a culture of innovation resting on six key pillars.

NATIONAL SECURITY IMPERATIVE

The reason for the NRO's existence arises from protecting the citizens of the United States from nefarious acts carried out against the U.S. and its citizens. The NRO was established as the threat of nuclear annihilation accelerated. In just over a decade before the establishment of the NRO in 1961, the Soviet Union became a nuclear power and engaged in the advancement of weapons systems that could deliver nuclear weapons to the United States with little warning. Throughout the first years of the Cold War between the U.S. and the USSR, the U.S. had little means to understand the development of those systems. With limited access to the USSR, the U.S. developed space reconnaissance systems to peer over the Iron Curtain and understand the extent to which Soviet nuclear weapons systems threatened the very existence of the nation.

The national security imperative born of the Cold War drove the National Reconnaissance Office to identify threats from Intercontinental Ballistic Missiles, Anti-Ballistic Missile systems, Strategic Long Range bombers, and the like to understand the strategic threat environment. In its second decade, the NRO expanded capabilities to understand international crises with timely and responsive technical collection. This capability allowed the U.S. to respond more rapidly to a crisis, as well as carry out activities to circumvent emerging crises.

More recently, the NRO has taken up new national security imperatives such as providing technical intelligence to those countering terrorism and to warfighters defending U.S. interests abroad. The NRO continues to develop highly innovative and technologically flexible collection systems to respond to new threats to U.S. national security and the safety of U.S. citizens and residents.

RISK-TAKING AND TOLERANCE

Just over a year before the NRO was established, the U.S. had recovered its first imagery from space. This effort did not come without significant risk-taking and tolerance. The U.S. attempted launches of Corona imagery collection satellites 13 times before the first mission was declared a success. More than a year and a half elapsed between the first attempt and the first success of the program, yet Corona program personnel steadfastly dedicated themselves to improving the Corona system. This level of persistence in face of doing something that had never been done before established an early cultural hallmark for the NRO of taking and tolerating risk.

Over the 60 years that the NRO has been in existence, its approach to risk management has afforded opportunities to develop dozens of new technologies and avenues for using space as a vantage point for technical intelligence collection. The NRO has consistently sought the most exquisite solutions that are technologically viable but also pushing the bounds of technology. Risk as a cultural hallmark of the NRO remains essential to the organization's success.

EMBRACING OPPORTUNITY

The use of space for intelligence collection emerged as a promising approach 15 years prior to the establishment of the NRO. It was only with the establishment of the NRO that the opportunities to collect intelligence from space grew into a fully integrated constellation of imagery, signals collection, and communications satellites. Along the way, the NRO embraced several technological opportunities including development of electro-optical and radar imagery, communications satellites, large data processing systems, and advanced signals collection systems. Each key technology provided the opportunity to embrace potential for better and more responsive intelligence collection.

The NRO has also consistently embraced management opportunities. With flexibilities arising from CIA authorities, the NRO engaged in novel acquisition approaches. The organization also embraced unique approaches to protect the secrecy of satellite systems. Systems integration and engineering emerged as key processes for advancing the nation's use of space for intelligence collection using NRO's satellites. The NRO avoided adhering to established policies and processes in favor of embracing new that would advance the organization's mission.

INDUSTRIAL PARTNERSHIPS

From its earliest days, the NRO has depended on the leading technology companies of U.S. industry to develop complex space systems. This unique industrial partnership is a key characteristic of the NRO culture. Industrial partners in the early years brought unsolicited solutions to intelligence collection challenges faced by the U.S. In developing systems, industrial and government employees worked together to develop new satellite systems in relationships of trust and respect.

Industrial employees continue to serve as essential members of the NRO community. They often work large portions of their careers on NRO projects. They bring fresh perspectives to the challenges of developing, launching, and operating space reconnaissance systems. In many instances, NRO employees from the space industrial base provide the "institutional memory" that is so important to successful organizations. Since its 40th anniversary, the NRO has recognized pioneers of national reconnaissance for their trailblazing contributions to development of NRO systems. The vast majority of those pioneers have been employed by industrial partners—a fact that confirms the importance of the industrial partnership in the cultural environment of the NRO.

CONNECTED LEADERSHIP

The NRO is one of the few organizations in the Federal Government where almost all employees have personal interaction with senior NRO leadership. Most employees assigned to work at the NRO can engage directly with the NRO Director. The DNRO does not have a security team or staff entourage that separates the director from the workforce. Most NRO directors and other senior leadership establish working relationships at all levels of the organization.

Historically, the NRO has been a "flat" organization with relatively few layers in its organizational structure. Additionally, most employees assigned to or working for the NRO have significant responsibilities given their grade levels. The structural efficiencies of the NRO organization allow for rich and rewarding experiences and interactions between multiple levels of the organization.

DEDICATED WORKFORCE

Above all else, the NRO culture is defined by a workforce that is dedicated to each other and to the success of NRO programs. In the early days of the NRO, those assigned to the organization worked long hours and days to develop the newest of technologies. Over the years, that work ethic has continued apace with significant devotion of NRO team members to organizational success. Launches at the NRO remain events that unify the workforce and afford mutual celebration of success. During the 40th anniversary of the NRO, banners read "One Team—Revolutionizing Space." These many years later, the dedication of this "One Team" of those working at the NRO should not be under-appreciated. The NRO workforce has grown and changed over the past 60 years, but it has retained one common feature, and that is dedication to *Supra Et Ultra*—together going "Above and Beyond" to protect the United States and its citizens and residents.

INNOVATIONS

GEOINT

IMAGERY FROM SPACE

BACKGROUND

In July 1955, the Soviet Union staged a deception that set the course for the United States to successfully obtain imagery from space. In 1954, Aviation Week reported that the Soviets had developed the Myasishchev M-4, or Bison bomber as it became known in the West. At the 1955 Aviation Day air-show held at Tushino Airfield northwest of Moscow, the Soviets carried out a highly effective deception operation. Knowing that western military attaches would attend the show, the Soviets flew 10 Bison bombers to impress the crowd. Unknown to those in attendance, the same 10 Bison bombers flew a second time over the crowd, followed by eight additional bombers. Thus, it appeared the Soviets had produced in a year's time a total of 28 bombers rather than the 18 they actually possessed—nearly a 30 percent difference. Based on the deception, the United States estimated that the Soviets would produce 800 bombers by 1960, a rate that would provide the Soviets with greater long-range bomber capability than the United States.

THE NEED FOR IMAGERY FROM SPACE

Although skeptical that the Soviets were capable of building more bombers than the United States, President Dwight Eisenhower did not have definitive intelligence to dispel the "bomber gap" in favor of the Soviets. He had approved the development of the U-2 in 1954, a jet-powered aircraft that could fly at speeds and altitudes that would evade Soviet air defenses. It proved to be just the resource needed to obtain definitive evidence of Soviet bomber production capabilities. On 9 July 1956, the U-2 obtained an image of an airfield near Leningrad with 30 Bison bombers. Subsequent U-2 imagery of other Soviet airfields confirmed the Bison bombers were limited to just that single base. The imagery served as conclusive intelligence for a new estimate that affirmed the United States maintained the advantage in the production of long-range bombers.

By the 1960 presidential election, two events took place that again raised concerns about the Soviets out-pacing the U.S. in strategic nuclear capabilities, this time the production of nuclear missiles. The first event occurred on 4 October 1957, when the Soviet Union launched the first man-made satellite known as Sputnik 1. Although the Soviets had publicly touted their efforts to launch a satellite, they surprised the world with the launch. Troubling to many was the realization that if the Soviets could launch an object into space, they could potentially launch a nuclear weapon against the U.S. or its other adversaries. The second event was the downing of Francis Gary Powers' U-2 over the Soviet Union on 1 May 1960. The downing of that flight led President Eisenhower to cancel all future overflights of the Soviet Union, briefly leaving the U.S. without one of its most reliable intelligence sources.

FIRST STEPS

However, the U.S. had already made a critical commitment to create a new intelligence collection system in 1954, the development of a satellite. The program, eventually known as Satellite Missile Observation System (Samos), got off to a slow start, but was accelerated after the Sputnik launch. In February 1958, President Eisenhower approved rapid development of an imagery satellite branching off the Samos program. After 13 unsuccessful launch efforts beginning in January 1959, the Corona satellite successfully returned imagery from space in August 1960. It was just in time to fill the void left by the cancellation of U-2 flights over the Soviet Union.

Corona was designed to take images of broad areas of the Soviet Union and other denied areas of the world of concern to U.S. policymakers. By the time of Corona's first successful launch, the United States was in the depths of the 1960 presidential election between Richard Nixon and John F. Kennedy. Kennedy alleged that the Soviets were out-pacing the U.S. in nuclear missile production while on President Eisenhower and Vice-President Nixon's watch. Just prior to Election Day, Corona had in just a few short weeks obtained enough imagery to dispel Kennedy's allegations of a missile gap. However, Corona was one the U.S.'s most closely guarded secrets and Eisenhower did not release evidence to dispel Kennedy's claims during the heated presidential election. The satellite imagery intelligence capability was too sensitive to reveal, even in a race for the U.S. presidency.

THE EVOLUTION OF SATELLITE IMAGERY SYSTEMS

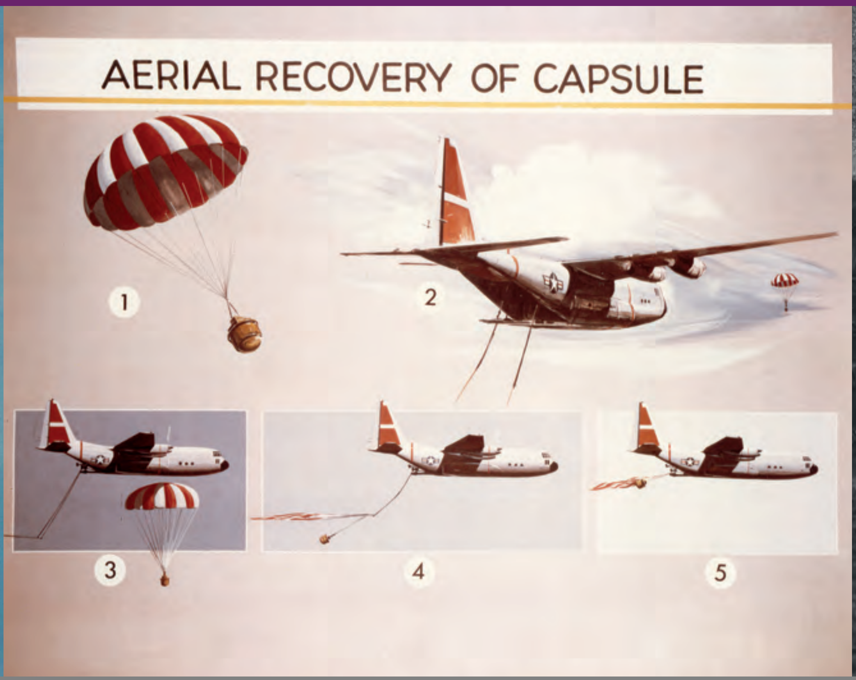
The Corona system, developed jointly by the CIA and Air Force, first could obtain images of objects about 40 feet in size, and by the end of the program, that capability improved to obtaining images from space of objects about six feet in size. Corona became an important source of collecting intelligence on issues of concern to U.S. officials such as adversaries' missiles, aircraft, naval vessels, and military installations. By 1971, the U.S. launched a follow-on satellite to Corona known as the Hexagon. Hexagon was one of the U.S.'s largest reconnaissance satellites, approximately the size of a train locomotive, with about 250 times more imaging capacity than the first Corona. It showed a vast improvement over Corona's imagery resolution with the ability to identify objects from space of about 1.5 feet in size.

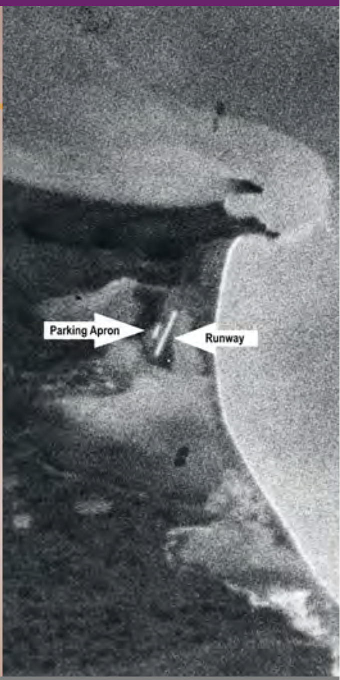
While Corona and Hexagon were excellent for identifying large objects from space to detect the capabilities of the U.S.'s adversaries, more detailed imagery granularity was needed. To that end, the NRO developed a high-resolution satellite, known as Gambit, to pinpoint specific qualities and characteristics of objects of interest. Launched first in 1963, the Gambit photoreconnaissance satellite could initially capture images of objects about 4 feet in size. Gambit's resolution improved to capturing objects about 2 feet in size when, in 1966, it was replaced by an improved Gambit-3 system. The Gambit-3 system evolved throughout its lifespan until its last launch in 1984. By then, the Gambit had the ability to image objects smaller than one foot in size. The combination of the broad area search satellites with the high-resolution satellites like Gambit allowed the U.S. to identify not only increases in Soviet weapons systems, but also technological improvements they were making to those systems.

The NRO spearheaded additional satellite reconnaissance capabilities that were key innovations for intelligence collection from space. For instance, in 1964, NRO launched an experimental satellite, known as Quill, which proved radar data could be processed into images. This established a foundation for the U.S. to image areas of concern where U.S. adversaries often used techniques and actions to disguise their capabilities or activities.

In 1976, the NRO's first electro-optical satellite, known as Kennen, was launched. Kennen produced the first digital images, rather than film-return images used on earlier satellites that had to be returned to Earth and processed. Kennen allowed the U.S. to capture images in "near real-time" rather than waiting days and weeks to process images from the earlier film return systems. With Kennen, the NRO provided an intelligence collection system that provided more timely intelligence for the President, senior policymakers, military commanders, and eventually the warfighter, starting in the 1990s and the Gulf Wars. Kennen also provided early investment in digital photography—a capability now used by most Americans every day. NRO has been, and continues to be, one of the original pioneers in the design and development of satellite technology and innovation.

CORONA



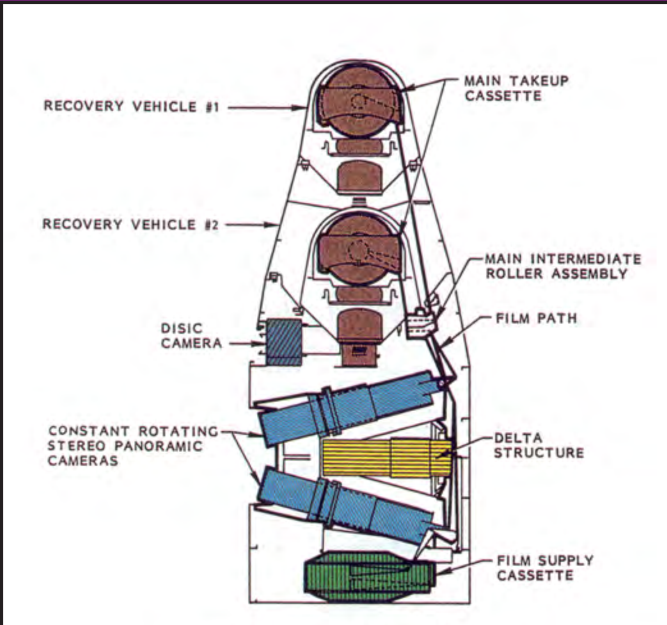


ORIGINS OF PHOTORECONNAISSANCE

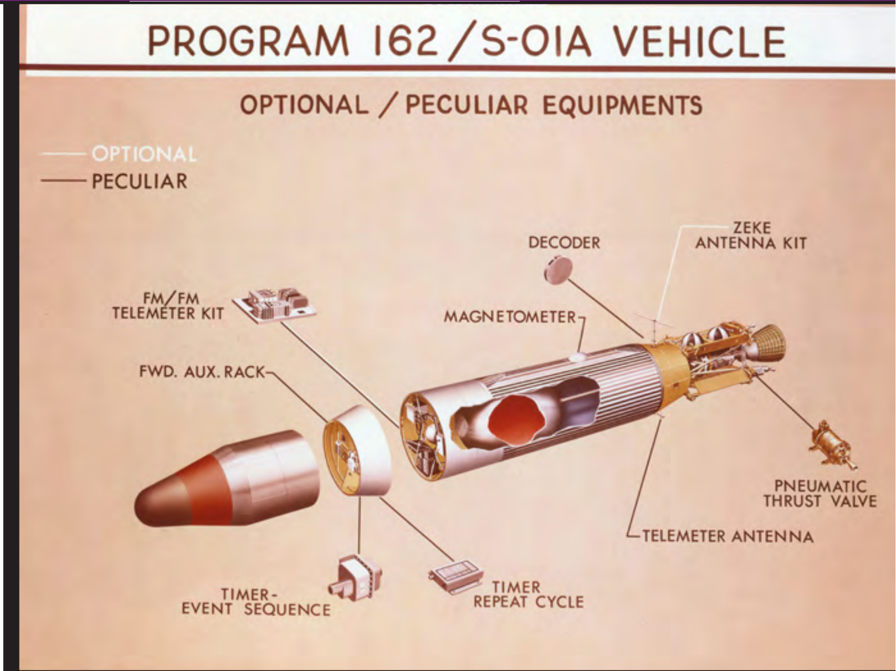
Following World War II, the United States identified the need for photoreconnaissance capabilities that could penetrate denied areas in the Soviet Union, Eastern Europe, and Asia. To that end, in February 1958, President Eisenhower endorsed the Corona project. Developed by the CIA and Air Force, Corona was a satellite imaging reconnaissance system that took pictures from space as it passed over denied territories like the Soviet Union. To obtain the images, the satellite would periodically "deorbit" and drop a film capsule, which was picked up in mid-air by a C-119 aircraft for transport back to CIA's National Photographic Interpretation Center (NPIC). Unlike its predecessors, the U-2 reconnaissance plane and the A-12 supersonic aircraft, Corona operated with far less risk since imagery was acquired from space. After Corona's first launch in 1960 until the program's retirement in 1972, the U.S. Intelligence Community (IC) refined photoreconnaissance under the program, which had an unprecedented impact on IC collection and national security policy.

PHOTORECONNAISSANCE SYSTEM ENHANCEMENTS

Corona operated for a little more than a decade, but it acquired photographic coverage of 750 square nautical miles of the Earth's surface and its early years were marked with rapid advancements. Between August 1960 - 1963, Corona went from a single camera system that produced a limited imagery resolution of 25 to 45 feet to a twin panoramic camera system that produced imagery with a resolution of 6 to 10 feet. Imagery users referred to Corona reconnaissance satellites by a Key Hole (KH) designator assigned to each new camera system as its capabilities were enhanced over time--starting with KH-1, KH-2, and so on. Notably, the KH-4 camera systems were the first to provide stereoscopic imagery, which allowed the IC to significantly increase collection content. The 30 degree convergent angle for stereo photography enabled measuring vertical and horizontal dimensions of the Earth's surface, which improved overall system dynamic balance and expanding mission durations.

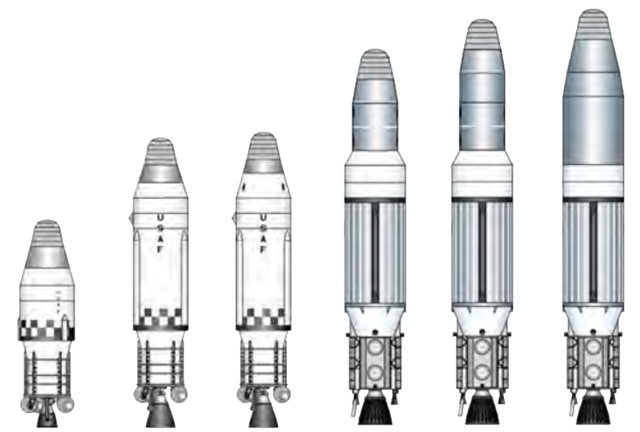


Major Components of the J-3 System



CONTRIBUTIONS TO NATIONAL SECURITY

The Corona program was operational from 1960 to 1972 and was instrumental in identifying military activities of interest to U.S. policymakers. As the only operational imaging-reconnaissance satellite until the launch of Gambit-1 in 1963, Corona imaged multiple targets in hostile areas yielding invaluable intelligence on Soviet targets. Corona identified and imaged all Soviet medium-range, intermediate-range, and intercontinental ballistic missile launching complexes. With Corona's imagery, analysts dispelled the myth that the U.S. lagged behind the USSR in missile production – the so called "missile gap." Using Corona imagery, analysts were also able to identify the main Soviet construction site for ballistic-missile-carrying submarines at Severodvinsk. The Corona program propelled the United States into an unparalleled position of dominance in photoreconnaissance capabilities that ultimately helped the U.S. win the Cold War. In 1995, President Clinton declassified the Corona program.

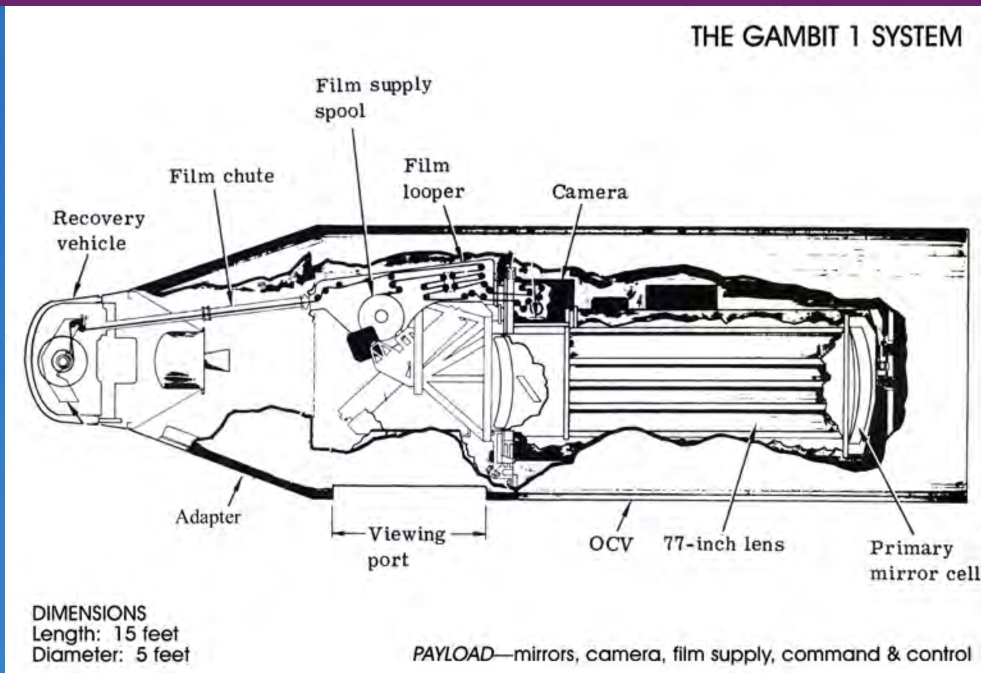


CORONA'S KH EVOLUTION

1959 – 1961: KH-1, KH-2, KH-3
Lens: 24-inch focal length
Film Length: 1,200 to 5,000 Feet
Image Resolution: 20 - 40 Feet
One Film Recovery Capsule

1961 – 1972: KH-4, KH-4A, KH-4B
Lens: 24-inch focal length
Film Length: 5,000 to 48,000 Feet
Image Resolution: 6 to 10 Feet
One or Two Film Recovery Capsules

GAMBIT 1 (KH-7)



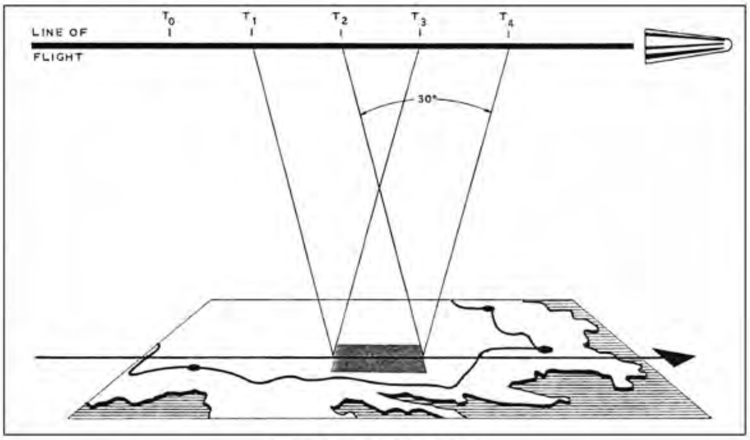
ORIGINS OF PHOTORECONNAISSANCE

Following World War II, the United States developed new photoreconnaissance capabilities to penetrate the denied areas in the Soviet Union, Eastern Europe, and Asia. President Eisenhower directed the Central Intelligence Agency to develop the U-2 reconnaissance plane, and later the more innovative supersonic A-12, in order to improve the nation's photoreconnaissance capabilities. He also directed the CIA to develop, in conjunction with the U.S. Air Force, the nation's first photoreconnaissance satellite, codenamed Corona. First launched in 1960, Corona operated with much less risk than photoreconnaissance aircraft and searched broad areas to capture incredibly valuable imagery while orbiting high above the Earth. These air and space platforms propelled the United States into an unparalleled position of dominance in photoreconnaissance capabilities that helped the U.S. win the Cold War.

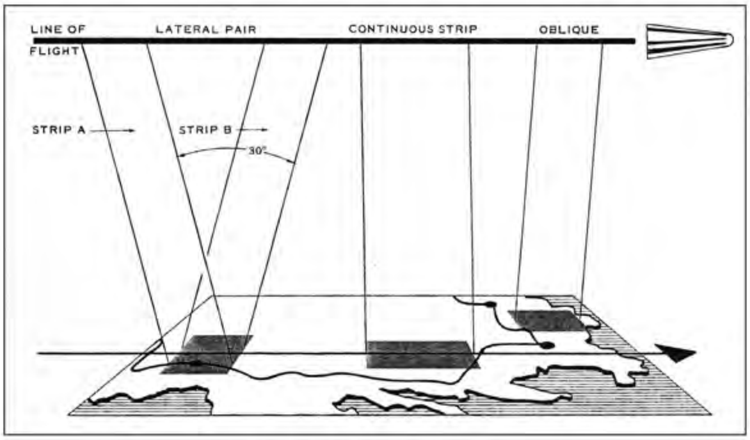
INTELLIGENCE NEED FOR PHOTORECONNAISSANCE

Although Corona provided the capability to search large areas from space, the U.S. still lacked high-resolution imagery. Approximately one year after the first launch of Corona, the National Reconnaissance Office began development of its first high-resolution satellite program, codenamed Gambit. The first Gambit system, launched in 1963, was equipped with the KH-7 camera system that included a 77-inch focal length camera for providing specific information on scientific and technical capabilities that threatened the nation. Intelligence users often characterized this capability as surveillance, allowing the United States to track the advancement of Soviet and others' capabilities. Over time, the Gambit program evolved into a second generation system.

Eastman Kodak Corporation provided an unsolicited proposal, named Sunset Strip, in the summer of 1960 to the Department of Defense program under the direction of Dr. Joseph Charyk, who would later become a Director of the National Reconnaissance Office. Kodak was already involved in the U.S. Air Force's Samos satellite program to develop reconnaissance satellites including photoreconnaissance satellites. After review, Dr. Charyk and other senior leaders found the proposal promising and initiated development of



STEREO OPERATION SCHEMATIC.



OPERATING MODES KH-7 CAMERA SYSTEM.

a high resolution satellite within a year of the initial success of the Corona photoreconnaissance satellite. By the time the NRO was formed in September 1961, the satellite was under development in the Air Force's Program A, now housed at the NRO. Less than two years later the Gambit satellite, named after an opening move in chess, provided the United States its first high-resolution imagery from space.

The United States depended on these search and surveillance satellites to understand the capabilities, intentions, and advancements of those who opposed the United States during the Cold War. Together they became America's essential eyes in space.

Gambit 1 provided the U.S. with close-in surveillance from July 1963 - June 1967

PROGRAM FACTS

Missions: 38 (28 successes)
Average Mission Life: 6.6 days
Imaging Days: 1-8.1 days
Altitude: 60-150 nautical miles
Roll Control: attitude control gas
Payload Weight: 1,154 lbs
Image Retrieval: Film Return Capsule

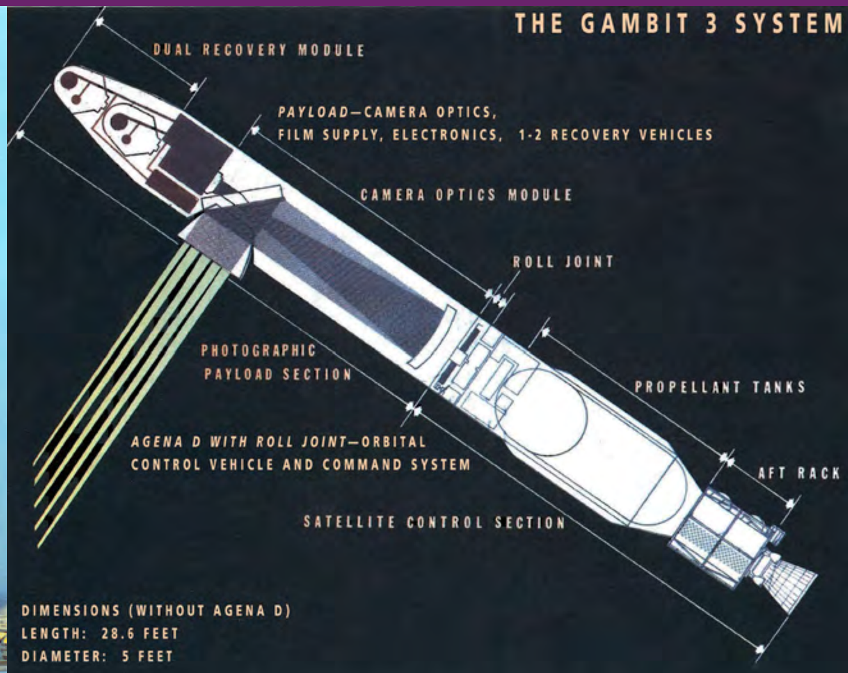
OPTICS/IMAGING

Aperture: 19.5 inches
Focal Length: 77 inches
Camera Developer: Eastman Kodak
Lens: f/4.0
Image Resolution: 3-2 feet
Film Length: 3,000 feet
Film Width: 9.46 inches

ADVANCEMENTS

Thin film permitted longer missions. The roll capability and stereo cameras enabled increased target acquisition and gave images a three-dimensional quality.

GAMBIT 3 (KH-8)



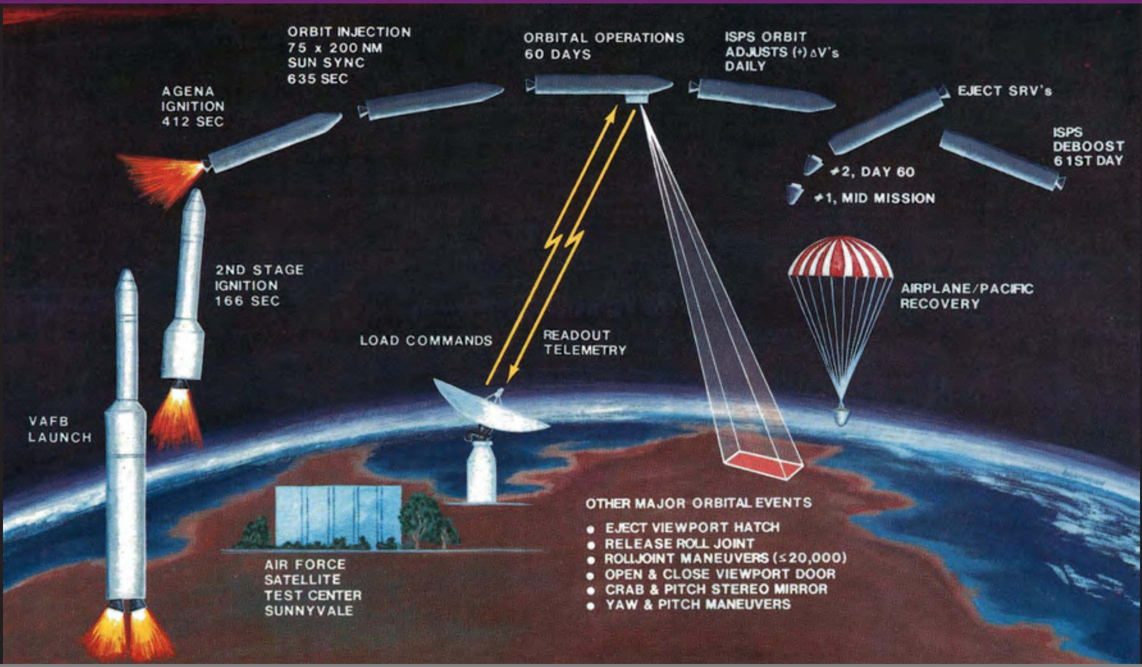
ORIGINS OF PHOTORECONNAISSANCE

Following World War II, the United States developed new photoreconnaissance capabilities to penetrate the denied areas in the Soviet Union, Eastern Europe, and Asia. President Eisenhower directed the Central Intelligence Agency to develop the U-2 reconnaissance plane, and later the more innovative supersonic A-12, in order to improve the nation's photoreconnaissance capabilities. He also directed the CIA to develop, in conjunction with the U.S. Air Force, the nation's first photoreconnaissance satellite, codenamed Corona. First launched in 1960, Corona operated with much less risk than photoreconnaissance aircraft and searched broad areas to capture incredibly valuable imagery while orbiting high above the Earth. These air and space platforms propelled the United States into an unparalleled position of dominance in photoreconnaissance capabilities that helped the U.S. win the Cold War.

INTELLIGENCE NEED FOR PHOTORECONNAISSANCE

Although Corona provided the capability to search large areas from space, the U.S. still lacked high-resolution imagery. Approximately one year after the first launch of Corona, the National Reconnaissance Office began development of its first high-resolution satellite program, codenamed Gambit. Over time, the Gambit program evolved into two different systems. The first Gambit system, launched in 1963, was equipped with the KH-7 camera system that included a 77-inch focal length camera for providing specific information on scientific and technical capabilities that threatened the nation. Intelligence users often characterized this capability as surveillance, allowing the United States to track the advancement of Soviet and others' capabilities.

Kodak had proposed four generations of Gambit satellites. The NRO's Air Force Program A, responsible for Gambit development, determined that the second generation did not provide significantly improved capabilities. Foregoing the second generation, Program A leadership opted for developing the third proposed generation, or Gambit 3, that would eventually allow the U.S. to obtain images from space of objects less than one foot in size. The fourth proposed Gambit generation required technological advances that were not possible at the time it was considered and therefore not pursued by the NRO's Program A.



LAUNCH, OPERATION, AND RECOVERY SEQUENCE FOR GAMBIT 3
Film-return photo-reconnaissance satellites returned the exposed film to Earth from space in a bucket with a heat shield designed to withstand the entry through Earth's atmosphere.

The second generation Gambit 3 photoreconnaissance satellite was equipped with the KH-8 camera system that included a 175- inch focal length camera. The system was first launched in 1966 and provided the U.S. with exquisite surveillance capabilities from space for nearly two decades.

The United States depended on these search and surveillance satellites to understand the capabilities, intentions, and advancements of those who opposed the United States during the Cold War. Together they became America's essential eyes in space.

PROGRAM FACTS

Missions: 54 (50 successes)
Average Mission Life: 31 days
Imaging Days: 5-126 days
Altitude: 65-90 nautical miles
Roll Control: mechanical roll joint
Payload Weight: 4,130 lbs
Image Retrieval: Film Return Capsule

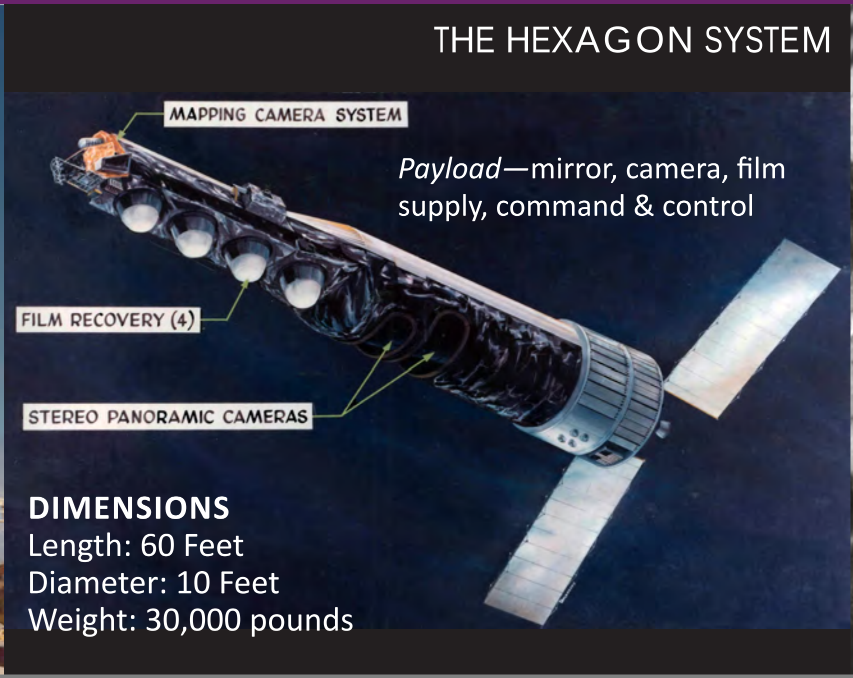
OPTICS/IMAGING

Aperture: 43.5 inches
Focal Length: 175 inches
Camera Developer: Eastman Kodak
Lens: f/4.09
Image Resolution: better than 2 feet
Film Length: up to 12,241 feet
Film Width: 5 inches and 9 inches

ADVANCEMENTS

The roll joint integrated with the attitude control resulted in extremely stable body rates, zero settling times, and improved expendables management—significantly increasing the number of targets it acquired.

HEXAGON (KH-9)



ORIGINS OF PHOTORECONNAISSANCE

Following World War II, the United States developed new photoreconnaissance capabilities to penetrate the denied areas in the Soviet Union, Eastern Europe, and Asia. President Eisenhower directed the Central Intelligence Agency to develop the U-2 reconnaissance plane, and later the more innovative supersonic A-12, in order to improve the nation's photoreconnaissance capabilities. He also directed the CIA to develop, in conjunction with the U.S. Air Force, the nation's first photoreconnaissance satellite, codenamed Corona. First launched in 1960, Corona operated with much less risk than photoreconnaissance aircraft and searched broad areas to capture incredibly valuable imagery while orbiting high above the Earth. These air and space platforms propelled the United States into an unparalleled position of dominance in photoreconnaissance capabilities that helped the U.S. win the Cold War.

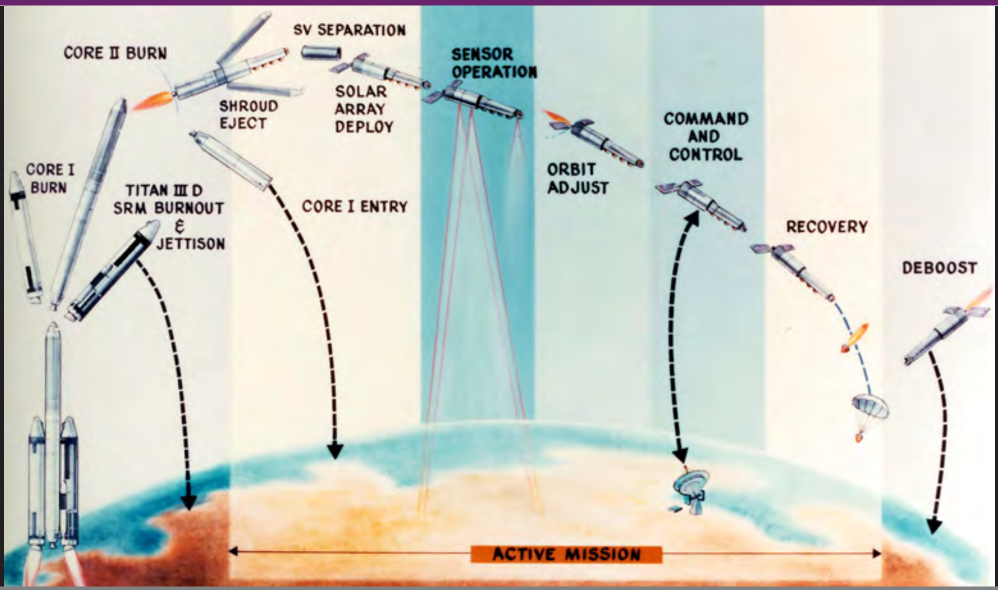
INTELLIGENCE NEED FOR PHOTORECONNAISSANCE

Although Corona provided the capability to search large areas from space, the U.S. still lacked high-resolution imagery. Approximately one year after the first launch of Corona, the National Reconnaissance Office began development of its first high-resolution satellite program, codenamed Gambit, first launched in 1963.

By the end of the 1960s, the CIA explored the development of a satellite that could obtain both wide area search imagery and high-resolution imagery under their Fulcrum program. If successful, the new satellite would replace both the Corona and Gambit satellites. The program was transferred to the NRO's Program B responsible for CIA satellite development efforts and renamed Hexagon. Although the Hexagon satellite provided significantly improved search capabilities, it did not match the high-resolution imagery capabilities of Gambit.

The NRO launched the first Hexagon satellite in 1971 to improve upon Corona's capability to search broad and wide denied areas for threats to the United States. The system sometimes carried a mapping camera to aid in U.S. military war planning.

The United States depended on these search and surveillance satellites to understand the capabilities, intentions, and advancements of those who opposed the United States during the Cold War. Together they became America's essential eyes in space.



LAUNCH, OPERATION, AND RECOVERY SEQUENCE FOR HEXAGON
After a parachute slows the bucket's decent, an airplane would capture the bucket mid-air.

Hexagon provided the U.S. with impressive broad-area search & mapping capabilities from June 1971 - April 1986

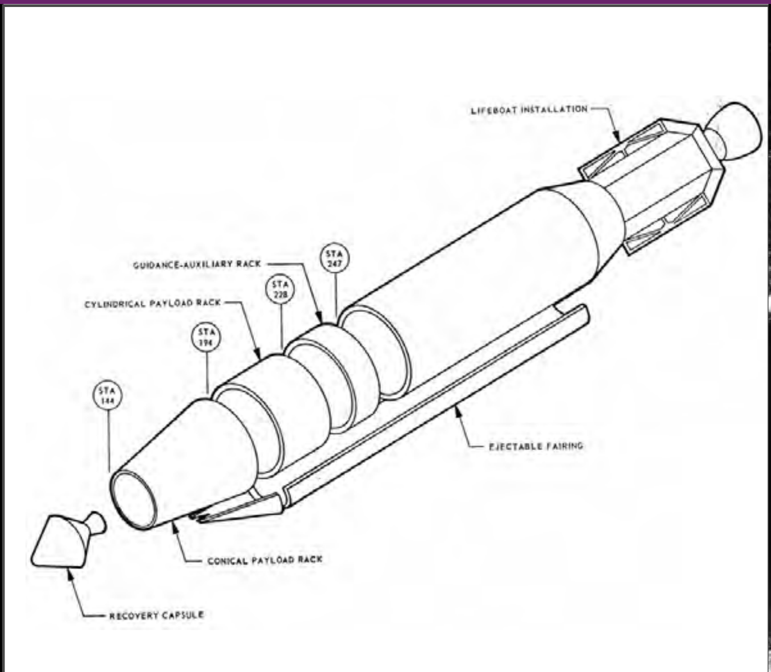
PROGRAM FACTS
Missions: 20, 12 with the MCS (19 successes)
Average Mission Life: 124-day average
Imaging Days: 31-270 days
Altitude: 80-370 nautical miles
Roll Control: attitude control gas
Payload Weight: 7,375 lbs
Image Retrieval: Film Return Capsule
Program Coverage: 877 million square miles

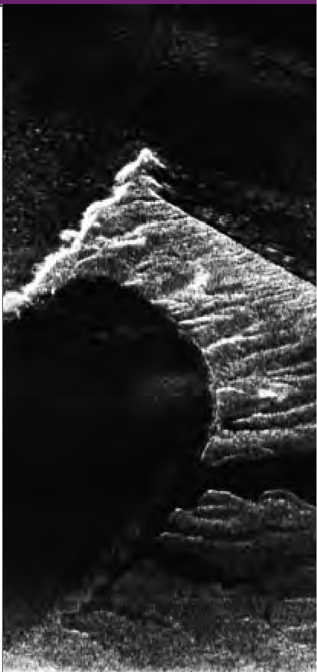
PANORAMIC OPTICS/IMAGING
Aperture: 20 inches
Focal Length: 60 inches
Camera Developer: Perkin-Elmer
Lens: f/3.0
Image Resolution: 2-3 feet
Film Length: 320,000 ft (60 miles)
Film Width: 6.6 inches

MAPPING OPTICS/IMAGING
Camera Developer: Itek
Lens: f/6
Focal Length: 12 inches
Image Resolution: 30-35 feet

ADVANCEMENTS
Hexagon, with its multiple recovery buckets and extended mission life, moved the U.S. closer to achieving continuous space imaging capability. Hexagon's primary panoramic camera provided improved search coverage and resolution. Hexagon's mapping camera provided global geodetic positioning, accurate point locations for military operations, and data for military targeting.

QUILL





ORIGINS OF QUILL

Despite the successes of the Corona and Gambit programs, they suffered some significant limitations. They could not obtain imagery at night or in poor weather conditions. Because both Corona and Gambit imagery was obtained via capsule returned from space, imagery from the systems could not be obtained quickly. The NRO was searching for solutions to those limitations. One of those was data transfer from orbit, which had proven successful with Sigint satellites such as GRAB.

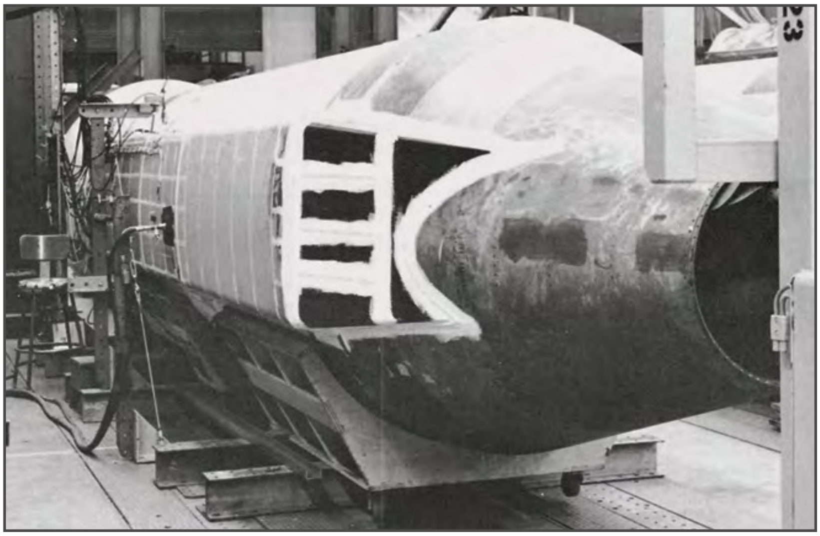
The other was the use of radar returns for manipulation into imagery, which the Army and Air Force had proven as a successful imagery approach using airborne platforms. Radar returns could travel through bad weather and night. Quill was born under these conditions in 1962.

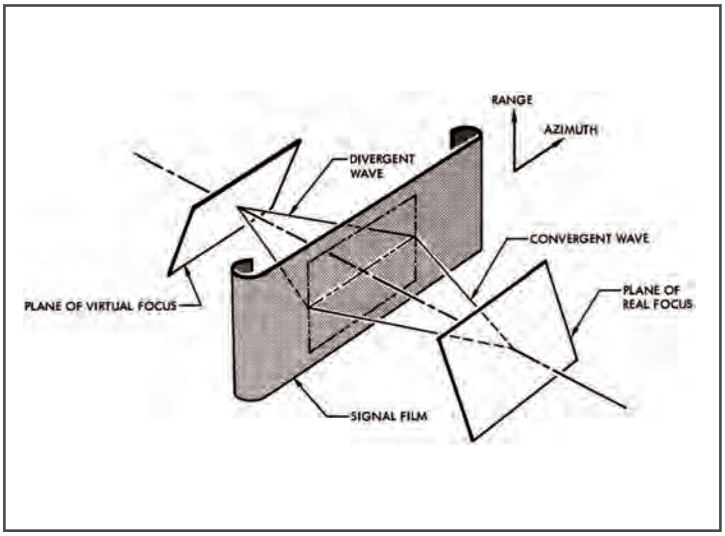
Major David Bradburn was assigned as the Quill Program Director. Bradburn worked diligently with Goodyear Aerospace and Lockheed Missiles and Space Companies to develop the Quill system. They were able to modify a number of existing radar and space vehicle components to integrate the system, saving time and money. By 21 December 1964 NRO launched the first and only Quill, and the launch was highly successful.

All the systems worked as planned. Quill was unique in that imagery would be derived from both film de-orbited from the space vehicle, using a Corona film-return system, and a radar data downlink that would be processed to create imagery on the ground. The two sources would then be compared for effectiveness. The first launch and operation of the satellite was so successful that a second launch was deferred indefinitely.

INTELLIGENCE NEED FOR QUILL

Quill was a trailblazer. The program demonstrated that the NRO could take existing sensor technology, modify it for use in space, marry it with other specialized hardware for national reconnaissance programs, and demonstrate the potential for new intelligence collection. Quill blazed the trail in technologies that could collect images day or night and through cloud cover. Quill was also run by then-Major David Bradburn, who would go on to become a senior leader of the NRO and major contributor to other successful program efforts at the NRO. The then-young NRO needed a program that could be turned quickly from concept to operation, and Quill blazed that trail leaving a stronger, more confident NRO.





On 21 December 1964, the first and only Quill satellite launched on a thrust-augmented Thor booster and an Agena upper-stage from Vandenberg. Quill's experimental mission would last only 96 hours. During that time the KP-II radar would operate no more than five minutes per orbit, and for no more than three orbits in succession. Three silver-zinc batteries powered the unit, providing a maximum of 80 minutes of synthetic aperture radar (SAR) collection. These parameters would allow the vehicle to achieve its mission goals. Vandenberg was equipped with video display monitors to determine if Quill was operating and transmitting properly. During Quill's seventh orbit, Vandenberg tracking station personnel began to receive radar returns on its monitors, declaring Quill operational. The data returned from Quill proved that radar imagery could be collected from space, and NRO determined a second experimental mission was not needed. Although the Quill experiment was a success, it would be several decades before radar satellites became part of NRO's satellite constellation.

QUILL

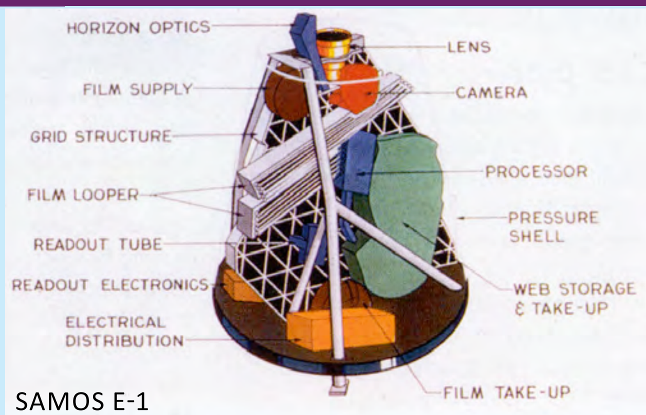
Experimental Radar Satellite - December 1964
Manufacturer: Lockheed & Goodyear

The proven flight package of a thrust-augmented Thor booster and an Agena D upper stage would carry Quill KP-II radar into space. Lockheed engineers expected the Agena to provide sufficient stability for its integrated KP-II payload to function effectively. This allowed them to opt for the simple solution of flush-mounting the radar antenna onto the Agena's outer surface. The 15-foot antenna occupied nearly the entire right side of the Agena, protruding about 2.5 inches from its surface once covered by a protective fairing.

ADVANCEMENTS

The Quill experimental radar imaging satellite was the first space-based system to use SAR to determine if radar could acquire ground images through clouds and in darkness. The SAR for this proof-of-concept satellite was developed as a way for the Air Force to assess post-strike damage in the event of a nuclear war. The technology was "off-the-shelf," adapted from a pulsed Doppler system being developed for a USAF reconnaissance aircraft.

KENNEN



SAMOS E-1


SAMOS E-2 LAUNCH


KENNEN LAUNCH - 1976

CRISIS DECISION-MAKING AND SPACE IMAGERY

Following the successful capture of imagery from space in 1960, the U.S. President and other leaders of the nation became increasingly dependent on space imagery for making key decisions. The early U.S. photoreconnaissance satellites, Corona and Gambit, shared common weaknesses with respect to supporting making decisions during international crises: both relied on film-return systems that meant captured imagery, at best, would be in the hands of decisionmakers within days of a crisis breaking out; and, both conducted relatively short, expendables-limited missions that required frequent launches, potentially leaving the U.S. with no satellite orbiting to obtain imagery as the crisis unfolded. The Strategic Air Command (SAC), in particular, was interested in rapid response imagery to assess escalating tensions that might lead to a nuclear weapons exchange with the Soviets. Thus the U.S. faced a daunting challenge in the late 1960s to develop a reliable near real-time imagery system.

CRISES RESPONSE PROVES INADEQUATE

Perhaps the first call for quicker photoreconnaissance from space arose from the 1962 Cuban Missile Crisis. The NRO orbited Corona systems near the end of September 1962 and the beginning of November that same year. Neither system could provide imagery during the October crisis. Another example was the Soviet invasion of Czechoslovakia in the fall of 1968, where a NRO satellite did obtain relevant imagery of Soviet troops massing on the Czech border, but the imagery was not available until the crisis was over and the imagery's relevance was overcome by events. Out of frustration over his inability to obtain clear intelligence on the placement of Soviet weapons systems in the Suez Canal zone during 1970, President Richard Nixon pressed for obtaining near real-time imagery from space. His administration was focused on limiting Soviet presence in the area, but had no reliable, time-sensitive source of intelligence on the Soviet activity. Near real-time imagery from space would address that issue.

EARLY NEAR REAL-TIME IMAGERY DEVELOPMENT

When the U.S. established the nation's first reconnaissance satellite development program that would eventually be known as Samos in 1956, program leaders proposed film-return satellite designs that would bear fruit in the Corona, Gambit, and Hexagon satellite systems. Samos program managers also pursued a film readout design, proposed by Eastman Kodak Company, which would provide imagery in a matter of hours, instead of the days and weeks required for the early film-return systems. The systems, known as E-1 and E-2, would rely on an on-orbit chemical photo development process—somewhat like the instant photography process that would become a commercial success for the Polaroid Corporation. Once the images were developed on orbit, an image scanner would scan the image and transmit segments of the image to ground stations where the image would be processed.

The system faced a number of daunting challenges given late 1950s and early 1960s technology. First, the chemical photo development process was new by earth-bound standards and was even more complicated in the vacuum of space. Second, the mechanics of developing an image and then scanning it in space required a very complex machine. Third, there was very limited storage and bandwidth for transmitting an image during the narrow windows when a satellite was within range of a ground station. The efforts to obtain space imagery using the film readout system proved too daunting, and the National Reconnaissance Office cancelled the film readout program elements after a single on-orbit operation of the E-1 proved the feasibility of the innovative technology, but also its limitations. The NRO turned its attention to improving film-return systems.

PERSISTENCE OF FILM READOUT TECHNOLOGY

The Samos film readout technology inherited by the NRO persisted despite the program's cancellation due to requirements from National Aeronautics and Space Administration (NASA) and the U.S.' efforts to send astronauts to the Moon by the end of the 1960s. One key requirement for successfully landing Apollo program astronauts on the Moon was detailed imagery of the Moon's surface. The Soviets had successfully imaged the back side of the Moon in 1959 using technology similar to the E-1 film readout system.

In 1963, NASA solicited proposals for a lunar imagery system that could image the Moon's surface to identify appropriate landing sites for Apollo program astronauts. Boeing Corporation partnered with Eastman Kodak for their proposal. The Boeing/Kodak proposal relied on the film development system used in the Samos E-1 system. NASA's source selection board judged the Boeing/Kodak proposal superior to the other four proposals primarily because its semi-dry chemical development process was less vulnerable in the vacuum of space compared to wet chemical processes proposed by the competitors. The Samos-based innovative film development process was incorporated into NASA's Lunar Imager system that successfully returned lunar images, helping to enable Apollo landings.

In July 1963, NRO's Program A successfully orbited the Gambit high-resolution imagery satellite. Gambit served as a companion to Corona. Whereas Corona obtained images of areas and objects of intelligence interest, the Gambit system imaged those areas and objects at high resolution to obtain intelligence specifics. Gambit eventually obtained imagery of objects and characteristics smaller than one foot in size, giving the U.S. a tremendous intelligence advantage in better understanding developments in the closed Soviet Union.

A number of crises prompted U.S. leaders to ask if satellite imagery was or could be available to assist in crisis decision making. In most cases, the NRO could not provide imagery quickly enough to support decision making during emergencies. The requests, though, prompted Program A officers to think of innovations to provide near real-time imagery that could assist in crisis decisions. They continued to investigate potential improvements in film readout technology first proven in the Samos program. More importantly, Program A officers advocated marrying such technology with the innovative high-resolution Gambit optical system. Such a marriage would significantly advance U.S. crisis management capability through timely high-resolution imagery. Program A called the system Film Readout Gambit or FROG.

KENNEN: THE NEAR REAL-TIME IMAGERY SOLUTION

In 1968, the CIA's Program B at the NRO began development of a highly innovative approach for obtaining imagery from space. Rather than relying on film at all, the Program B engineers pursued development of a digital optical system. Earlier proposals for putting a video camera in space preceded Program B's thinking on non-film based imagery systems. Their approach was highly unique and required a completely new kind of camera system—one not even developed for use on Earth at the time.

Program B's approach required a number of technological breakthroughs for the system to work. The first was the optical system itself. CIA pursued the first two types of new digital technology: a photo diode array and a photo transistor array. Either approach would avoid many of the pitfalls of depending on film-based systems in space and would open the possibility of reducing the time to obtain space imagery from weeks and days to hours and minutes. Both approaches required major technological breakthroughs to achieve revolutionary near real-time imagery capability from space.

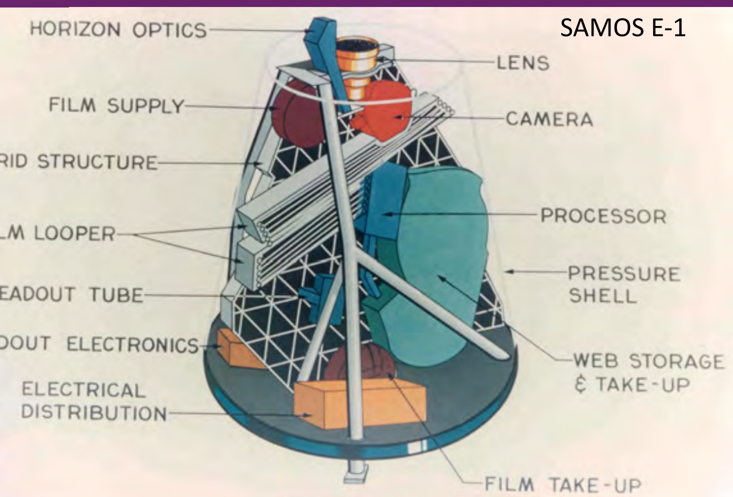
Another significant innovation advanced by Program B was the introduction of relay satellites to assist in transferring the image from the imagery satellite to the ground station, where it could be processed and exploited. Previous approaches to more rapid imagery from space had been hampered by the short time in field of view of ground stations. The relay satellite solved this problem, as it was placed in a geosynchronous orbit within the constant field of view of the ground station.

Program B developed the program concept so that by the early 1970s they were confident to invest in the new innovative digital imagery program. Program A continued to advocate for their FROG system, arguing that it was less risky and could be procured more quickly. Elements of the Department of Defense, CIA, and Office of Management and Budget debated the merits of both programs. Eventually, both choices were presented to President Richard M. Nixon, and he approved the Program B proposal, which would be known as Kennen, on 23 September 1971. The name Kennen was chosen by NRO Deputy Director Bob Naka adopting the German verb "to know" as the program name.

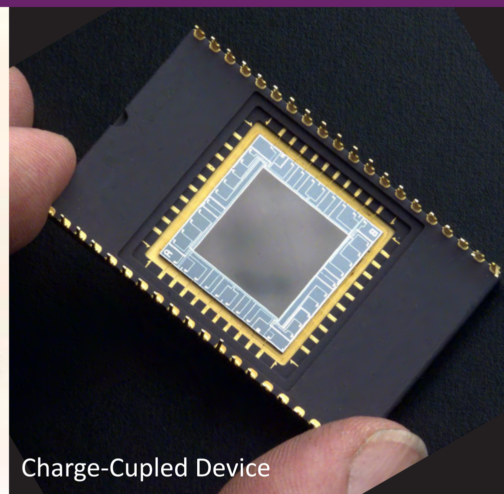
Nixon approved the program with the understanding that it would provide imagery by the end of what he hoped would be his second presidential term in 1976. Program B did launch the first Kennen satellite in December 1976, but the first imagery was delivered to newly inaugurated President Jimmy Carter at his first intelligence briefing after being sworn in as President in January 1977.

Program B's initial efforts established a foundation for development and adoption of the optical systems' charge-coupled device (CCD), a completely new technology for imagery. The charge-coupled device would evolve further for commercial use in digital video cameras and other commercial applications after the NRO's heavy investment in CCD technology. A new era of digital photography began.

DIGITAL IMAGERY



SAMOS E-1


Charge-Cupled Device


Kennan Launch - Dec 1976

EARLY U.S. ELECTRONIC SPACE IMAGERY EFFORTS

The the Air Force's satellite reconnaissance efforts originated from the WS-117L program, which was created in 1954 by the Air Research and Development Command. One of the programs started in WS-117L was the Samos project, which began development of satellites with both Imint and Sigint payloads and investigated both film-based and electronic imagery systems. In late 1957, it was decided that technology for imagery transmission was still years away, and the film-based system was much closer to being realized. The two projects were separated, and the film-based project was broken away into what soon became the Corona program, which started returning imagery to Earth three years later.

Meanwhile, scientists and engineers continued to work on electronic imagery with Samos. They developed an analog system, called the E-1, that worked but had significant shortcomings that proved too insurmountable to be used in an intelligence satellite. Early studies showed the time needed to transmit the images to Earth was the main impediment to making it useful for a satellite orbiting the planet.

APOLLO PROGRAM AND ELECTRONIC SPACE IMAGERY

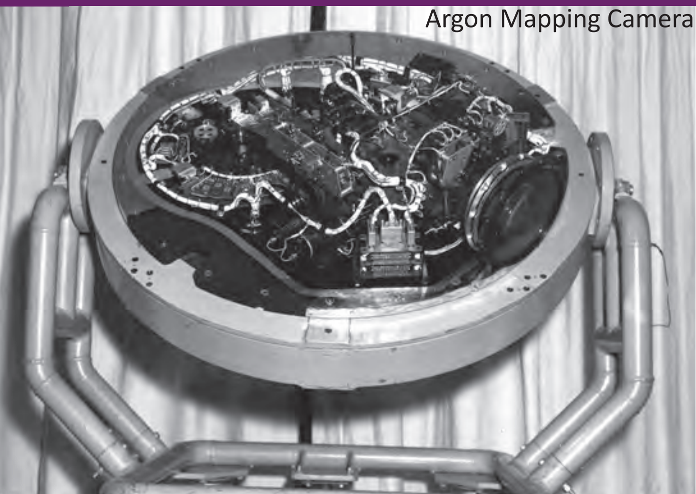
In the 1960s, when NASA began planning for their Lunar Orbiter to map the Moon's surface for landing sites for the Apollo program, the NRO allowed Eastman-Kodak to propose a candidate for the NASA program using the E-1 system that was developed for the NRO. Although the Kodak proposal was the most expensive candidate, it had proven technology and so was chosen by NASA because the other proposals all required testing and would take far longer, with success not guaranteed. The Lunar Orbiter succeeded in mapping 90% of the Moon's surface, enabling NASA to choose the best landing sites for its missions. Without the NRO's help, Neil Armstrong's "one giant leap" may have been delayed, and President Kennedy's call to visit the Moon before the end of the 1960s may not have been fulfilled.

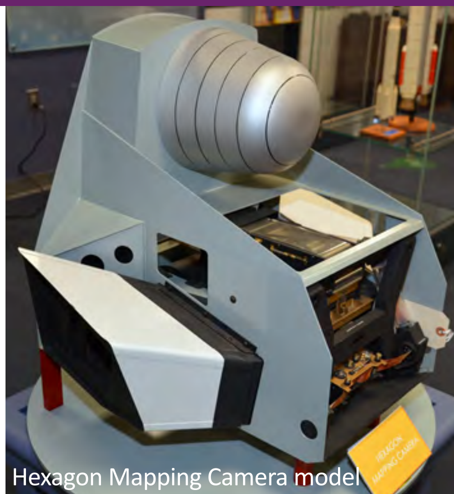
WHY WE USE IT

Still, an intelligence satellite orbiting the Earth needed a much faster data transmission rate than was provided by the analog E-1 camera system, and that could not be realized until digital imagery systems were developed. Actual "digital" imaging had been around since the 1920s, but the process was cumbersome and time consuming. The NRO continued its research, and using both in-house advances and data from the private sector, such as the invention of the charge-coupled device in 1969 by scientists at Bell Labs, the technology soon reached a tipping point. By 1971, all of the pieces had been put into place, and in September, President Nixon authorized the commencement of the NRO's electro-optical imagery program, which would eventually produce the KH-11 Kennen satellite.

It would be another five years of long, hard nights and weekends for NRO engineers, but in December 1976, the NRO finally launched the world's first electro-optical imagery intelligence satellite, and imagery's Digital Revolution began. On 20 January 1977, the day on which Jimmy Carter was inaugurated President, the KH-11 Kennen satellite became operational and beamed the world's first near real-time intelligence imagery to Earth, much to the chagrin of President Ford, who had hoped to get the first image before he left office, consistent with Richard Nixon's desire to see the satellite operate by the end of what would have been his second presidential term. Since that day, the NRO has continued to make groundbreaking advances and has produced significantly better imagery satellites time and again. The digital electro-optical imagery satellite system continues to be a key component in the NRO constellation and will continue to be for decades to come.

MAPPING CAMERAS


Argon Mapping Camera


Hexagon Mapping Camera model


Hexagon Mapping Camera image

In the early 1960s when U.S. satellite activity was taking shape and the NRO was formed, it quickly became apparent that imagery needed for strategic intelligence purposes and imagery needed for mapping requirements were not always compatible. At the time Corona first orbited, the U.S. military was still heavily dependent on captured World War II-era German maps for planning defenses against the Soviet Union. Those maps were both imprecise and incomplete. The military needed new imagery to update their maps, but strategic planners had more pressing concerns, such as the number of bombers and nuclear missiles the Soviets had in their inventory.

While the development of reconnaissance satellites had the utmost priority with U.S. decision makers, the country could not afford to have multiple programs trying to build basically the same type of system; that was precisely one of the reasons the NRO was formed in the first place. With this in mind, the NRO recognized that satellite vehicles could be configured for different collection purposes, so they could accomplish different missions without developing an entirely different system.

ARGON

The Air Force developed their own mapping and charting system, designated the E-4, in the Samos program. While a few working E-4 cameras were eventually built, none ever flew because of a lack of rockets to launch them into orbit, which were distributed to programs with higher priorities. Meanwhile, the NRO worked with the Army on the Argon project that incorporated a mapping camera into the Corona satellite platform to provide imagery for improving mapping capabilities. Integrating a new capability into an existing platform demonstrated the integration philosophy of the NRO.

Argon operations were not really part of the Corona program but generally were treated as such because of equipment and operational similarities. To perform its cartographic function, Argon flew much higher than Corona and used a much shorter (3-inch focal length) lens and a different camera mechanism, but in most outward respects, it was indistinguishable from a Corona-C or C′ camera. Between 1961 and the end of 1964, 13 Argon launches were attempted. Six missions were counted as successful to some degree, and the remainder failed completely, most of which were attributed to launcher failures. Notably, six of the first seven mission attempts failed, but only one failure occurred (on 26 April 1963) in six launches during the last two years of Argon operations.

In 1964, Corona engineers began developing the DISIC camera—which had a three-inch focal length lens—that provided a star-calibration capability that was largely unaffected by the orientation of the orbital vehicle. The earlier stellar indexing system had become ineffective whenever the main camera was positioned so that the stellar camera looked toward the sun; in DISIC, one camera was always pointed at least 90 degrees away from the sun. The incorporation of DISIC in combination with a variety of other improvements in camera precision effectively created a mapping capability in Corona J-3 that finally obviated any need for flying dedicated mapping missions. With the addition of DISIC to the Corona system, the requirement for additional Argon missions or a successor to Argon vanished.

HEXAGON

First launched in 1971, the Hexagon system was the replacement for Corona, which could not be appreciably improved without major system restructuring and enhancements. Since the expected benefits of an improved Corona were not that significant, the NRO decided to instead start from scratch and develop a brand new search system to take full advantage of the advancements that had been made in satellite and launcher technology over the previous decade. The result was a significantly improved system, both in terms of size and capabilities. The new "Big Bird" satellite was as big as a bus, could carry 10 times the film load of Corona, and could stay in orbit for up to nine months.

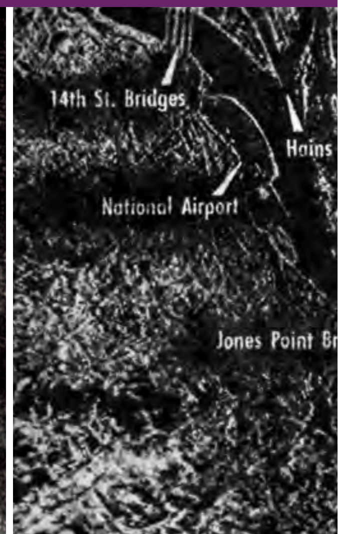
Being the replacement for Corona meant that Hexagon was the natural vehicle to carry the next government mapping camera. The first four Hexagon satellites flew with just their reconnaissance cameras aboard, while the new mapping camera was being developed. But the next eight Hexagon vehicles all carried the Hexagon Mapping Camera (MCS). The MCS did not fly on the last four Hexagon missions.

One of the most significant improvements over the Corona system was that because of the size of the Hexagon flight vehicle, engineers were able to incorporate the MCS into the standard mission vehicle without removing any of the basic components. The extra MCS cameras and film load could be attached to the Hexagon vehicle without any reduction in Hexagon performance. Therefore, the MCS was able to fly along with the Hexagon's reconnaissance cameras/film, so those flights could accomplish both missions. This was a complete departure from the Corona program, where the Argon system had to replace the Corona cameras to fly. The Hexagon MCS was also so reliable that it never caused any malfunction or delay in the Hexagon's primary reconnaissance mission.

Over the course of eight flights, the MCS collected 48,000 feet of highly accurate mapping film covering about 104 million square nautical miles. The MCS provided better than a four-fold improvement in accuracy, and more than a ten-fold improvement in resolution, over the previous best KH-5 (Argon) mapping camera. This data provided far better geographic positioning and elevation information for the nation's mapping community, allowing them to produce more and better maps and targeting data for tactical and strategic weapon systems.

Hexagon flew 19 successful missions from June 1971 through October 1984. The 20th and final Hexagon mission was launched on 18 April 1986, but it experienced a booster malfunction nine seconds into flight and was destroyed, becoming the only unsuccessful Hexagon mission. The Hexagon MCS was declassified along with the Hexagon and Gambit programs by DNRO Bruce Carlson for the NRO 50th anniversary celebration on 17 September 2011.

RADAR IMAGERY



BEGINNING THE TRADECRAFT

Radio Detection and Ranging (RADAR) was developed in the early 20th century from theoretical work and basic experiments of Scottish and German scientists from the late 19th century. Many countries began to seriously investigate the principle in the 1930s, and most of the major participants in the Second World War had some form of usable radar system. Many historians credit radar as the single most important ingredient in the Allied victory in the Battle of Britain in 1940.

INVESTIGATING A NEW DISCIPLINE

However, static radars can only measure signals and cannot "paint a picture." Radar imagery can only be produced by collecting returns along a path by a moving radar. So it was many years before radars could be made small and mobile enough to produce radar imagery. In April 1960, the U.S. Army unveiled pictures of American cities taken at night and through clouds using a synthetic aperture radar system mounted in a small aircraft (SAR is a scientific technique that simulates a much larger receiving antenna, which improves the resolution of the resulting radar "picture," making it possible to put radars in aircraft and satellites). This emerging technology was receiving significant interest from people and organizations involved in reconnaissance activities. The Air Force was particularly interested to see if this technology could be used to provide usable post-strike damage assessments without having to wait for appropriate conditions for optical sensors.

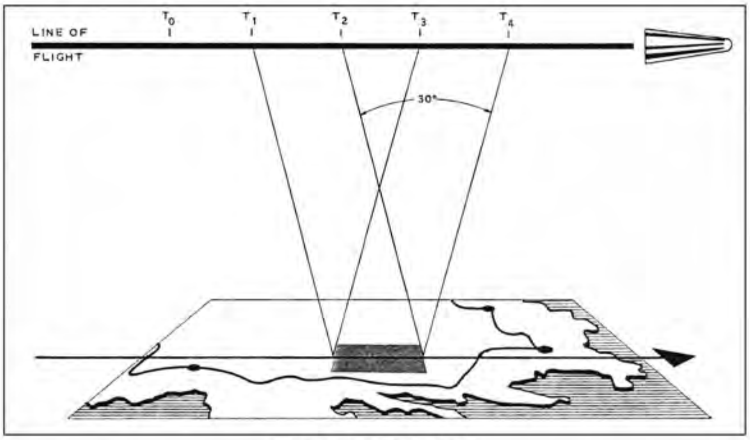
QUILL

In late 1962, DNRO Joseph Charyk designated Maj David D. Bradburn (who would later become a Major General and head of NRO's Program A) to lead a project named Quill to determine if collection of usable SAR imagery from satellites was feasible. Using "off-the-shelf" equipment and technology, Bradburn was able to quickly and efficiently get the program off the ground. Quill collected radar returns on tape spooled in the satellite, while also transmitting the data back to collection sites on Earth. The first (and only) Quill launch occurred on 21 December 1964. The satellite worked so well that a second planned launch was cancelled, since all of the program's objectives had been met during the first launch.

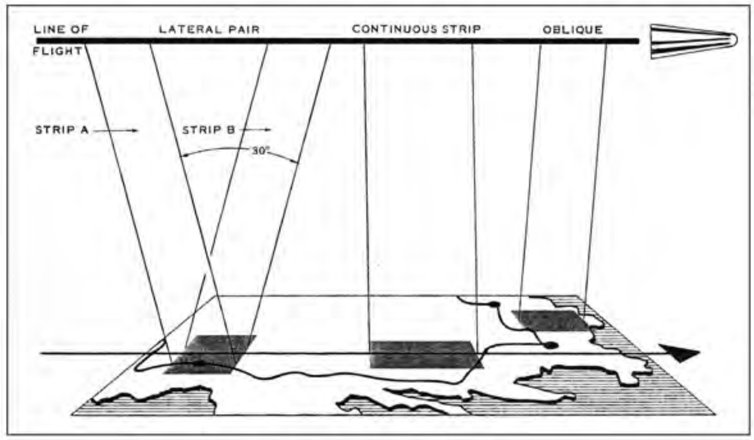
THE PATH FORWARD

In the final evaluation of the experiment, it was found that usable SAR imagery could indeed be collected from satellites. However, the resolution of the Quill imagery was relatively poor, and it did not provide the necessary intelligence needed to justify a new satellite system. While the NRO moved on to more pressing needs, it never forgot about radar imagery, and its engineers and scientists continued to explore this new technology. It would be many years before the Intelligence Community would be able to build a usable radar satellite with sufficient resolution; it was not until 9 June 2008 that the DNI declassified the fact that the U.S. operated an effective radar satellite reconnaissance system.

STEREO IMAGERY



STEREO OPERATION SCHEMATIC.



OPERATING MODES KH-7 CAMERA SYSTEM.

IT IS ALL IN THE VIEW

Stereo imagery is the result of taking two images of the same spot from slightly different locations, resulting in slightly different perspectives, and viewing each of those images separately with each of your eyes or viewing a combined picture with special goggles/glasses. The resulting view gives depth to the scene and a 3D perspective, and it gives the viewer a much more detailed view of the scene, allowing the viewer to see things that could be missed from simply viewing a single image because imagery is a two-dimensional representation of a three-dimensional space. For non-imagery analysts, the most common experience of stereo viewing is watching a 3D movie or using virtual reality goggles.

WHAT IT PROVIDES

Viewing imagery in stereo provides the ability to perceive height and depth in remotely sensed data. NRO tasking software determines the correct acquisition parameters for stereo imagery with math models that ensure the proper differential perspectives of the two images. Taken from orbit, the aim points must be precise; otherwise the resulting stereo pair would not register properly and would appear blurry.

WHY WE USE IT

In the Intelligence Community, NRO-provided stereo imagery has been used for decades by imagery analysts to differentiate fine details in a scene. It is particularly useful for identifying and analyzing tall, thin objects, such as antennas and towers, and also in analyzing very small objects that provide little detail in a 2D perspective. Cartographers and geospatial analysts use stereo imagery to produce maps and digital elevation models. Stereo imagery has the added benefit of producing very accurate positional measurements required for certain operational applications.

In the early days, exploitation of stereo images was a difficult, haphazard technique of physically aligning the hard-copy images below a special viewing tool that had to be constantly adjusted to look at different points on the images. With today's advanced computers, softcopy exploitation is much more easily achieved, although the process takes a great deal of computer power and memory.

WHO ELSE USES IT

In the private sector, stereo imaging has proliferated into many new areas in the last two decades. Stereo imaging is used in art, education, medicine, scientific/engineering research, space exploration, and of course, entertainment. It is used by doctors to view inner parts of a body before surgery. It is used extensively by eye doctors for both diagnosis and treatments. It was used by NASA in the Mars Exploration Rover missions. Today's nascent virtual reality business is built on stereoscopic imaging principles, and everyone expects that business to boom as the technology matures. It may be years before we can all play the chess game that Chewbacca and C-3PO played in Star Wars (which was more holography than stereo imagery, though the concepts are similar), but those days will be with us before we know it.

INNOVATIONS

SIGINT

GRAB

SIGNALS COLLECTION HUT

BACKGROUND

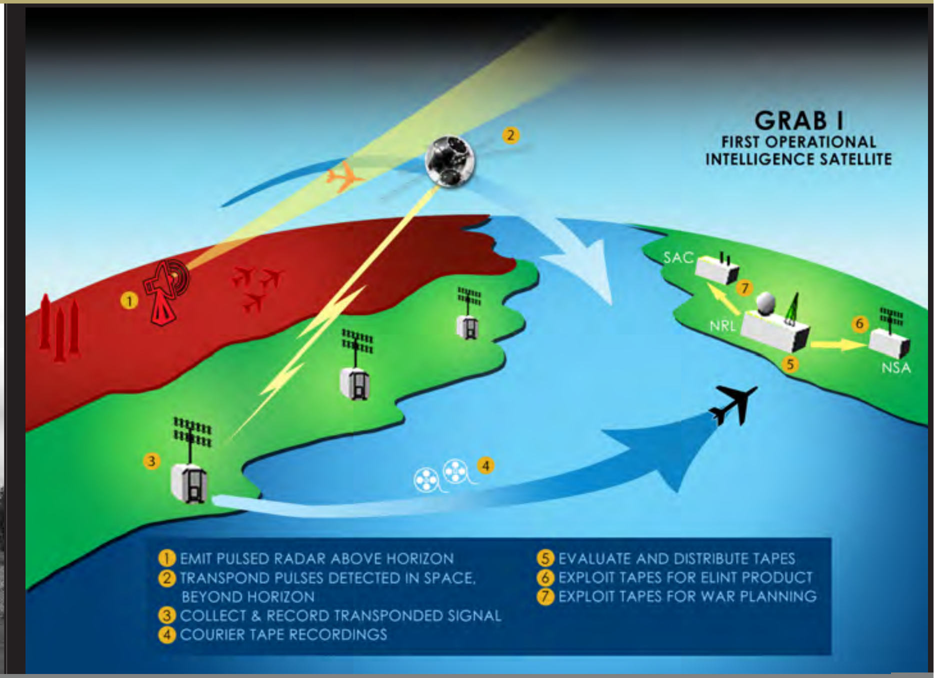
In March 1958, Reid Mayo, an engineer at the Naval Research Laboratory (NRL), passing time while stuck in a restaurant during a Pennsylvania snowstorm, came up with the novel idea of mounting a periscope-radar detector on a Vanguard-like satellite. After returning to Washington, Mayo pitched his idea to NRL's electronic countermeasures chief and shortly thereafter the concept was approved by the Director of Naval Intelligence, and the Galactic Radiation and Background (GRAB) project became a reality. In August 1959, President Eisenhower formally approved Mayo's project, which by then became classified with the code name "Tattletale."

NAMES CAN BE MISLEADING

The GRAB satellite was a cover name that portrayed the program's purpose as a research project measuring radiation in space. In fact, the GRAB satellite was equipped with scientific instruments and a receiver that could detect pulsed-radar signals emitting from Soviet air defense systems. The intelligence yielded from GRAB played a vital role in U.S. national security at the height of the Cold War. While GRAB was the first electronics intelligence (Elint) satellite to be launched into space by the U.S., it only operated from 1960-1962. However, Poppy, GRAB's successor, operated from 1962-1977. The Director of CIA (D/CIA) authorized limited declassification of GRAB in 1998. In 2004, the D/CIA declassified limited facts about Poppy's existence.

UNWANTED INTERNATIONAL CONTROVERSY LEADS TO ACTION

On 1 May 1960 when Frances Gary Powers' U-2 high-altitude reconnaissance aircraft was shot down over the Soviet Union, President Eisenhower cancelled all U-2 flights over the region. Four days after the U-2 was shot down, President Eisenhower approved the first GRAB launch. GRAB was successfully launched into orbit on 22 June 1960 from Cape Canaveral, Florida on a Thor Able-Star rocket. NRL attempted four additional GRAB missions between 1960 and 1962, but only one was successful. However, lessons learned from GRAB's two successful launches were foundational to the development of its first cousin and successor, Poppy (sometimes referred to back then as the polar flower in the sky).



HOW GRAB WORKED

GRAB satellites featured Elint antennas that provided reception of radar signals. A larger and separate turnstile antenna received ground commands, telemetry, and Elint data. When terrestrial radar emitted pulsed-radar signals above the horizon, GRAB satellites collected each radar pulse signal in a specified bandwidth and transmitted a corresponding signal to an NRL control ground hut within its field of view. The hut's antenna masts contained two upper bays of 10-element yagi antennas that received telemetry (108 MHz) and four lower bays of 10- element yagi antennas that transmitted commands and received Elint (139 MHz). Personnel at the ground control huts then recorded data from GRAB and dispatched tapes with that data, initially to NRL, and then to National Security Agency (NSA) and the AF Strategic Air Command. NSA and SAC then exploited the data to develop technical intelligence about Soviet radar. As mentioned, only two of GRAB's five launches were successful, and the program was realigned under the newly-formed NRO.

SATELLITE PROGRAMS ALIGNED UNDER NRO

When NRO opened its doors on 6 September 1961, its charter was to manage the newly created National Reconnaissance Program (NRP), which consisted of all consolidated satellite and overflight reconnaissance projects for the IC. Consequently, in 1962, NRL's Elint satellite activities were realigned under NRO as were CIA and Air Force space programs. These projects became known as NRO's alphabet programs. Program A represented the Air Force, Program B represented the CIA, and Program C represented Navy programs, including GRAB and Poppy. Under Program C, the Navy continued NRL's Elint satellite collection with the enhanced Poppy, GRAB's successor. The GRAB-2 program was terminated in August 1962, and on 13 December 1962 the Air Force used a Thor Agena-D launch vehicle, to carry Poppy 1 into orbit from Vandenberg Air Force Base in California.

GRAB AND POPPY LASTING LEGACY

Early NRO Elint satellite programs were a critical element of U.S. technical reconnaissance operations during the 1960s into the 1970s. Before development of these systems, technical intelligence about Soviet air defenses was limited to airborne and ground-based collection platforms that could only access radar site data from less than 200 miles. GRAB's lasting contribution was demonstrating that Soviet air defense networks had far more radars than SAC knew about, prompting SAC to change their offensive strategy for fighting nuclear war. Collections from GRAB, and later Poppy, supported a wide range of other intelligence applications as well. For example, they provided SAC not only with detailed information about Soviet air defense equipment and locations but provided valuable ocean surveillance data to Naval operational commanders. When GRAB and Poppy data were combined with Corona's satellite images, a more complete picture emerged about Soviet military capabilities, which supported military and senior policymakers with making informed decisions. GRAB and Poppy innovations have and will continue to impact development of increasingly sophisticated capabilities into the 21st century, which are needed today more than ever.

ADVANCEMENTS

GRAB satellites featured Elint antennas that provided reception of radar signals. A larger and separate turnstile antenna received commands, transmitted telemetry, and transmitted Elint data.

The National Security Agency and Strategic Air Command exploited the data to develop technical intelligence about Soviet Radar.

GRAB

Successful Missions: 2
Size: 20 inches in diameter
Codename: Tattletale
Objective: Collect Elint

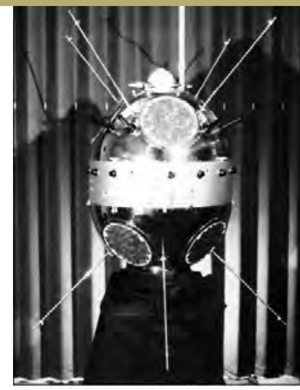
GRAB MISSIONS:

LAUNCHES

GRAB 1	22 JUN 1960	THOR ABLE STAR
	30 NOV 1960	THOR ABLE STAR (FAILED)
GRAB 2	29 JUN 1961	THOR ABLE STAR
	24 JAN 1962	THOR ABLE STAR (FAILED)
	26 APR 1962	SCOUT (FAILED)

POPPY

SIGNALS RECEIVING CONSOLE



ORIGINS OF SIGNALS INTELLIGENCE

The Galactic Radiation and Background electronic signals intelligence satellite was the world's first successful reconnaissance satellite.

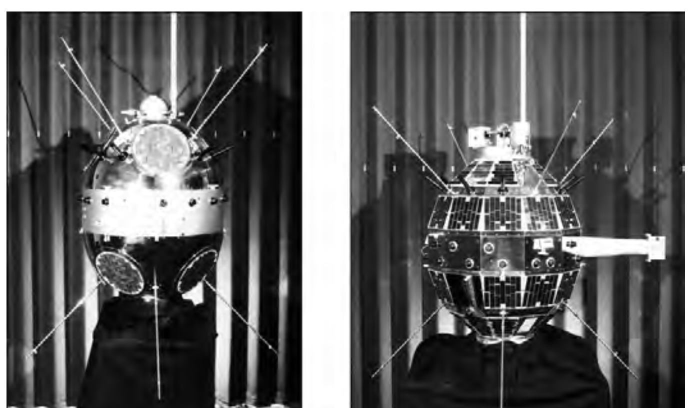
The Poppy reconnaissance satellite was GRAB's successor. In 1962 the Naval Research Laboratory, by then part of NRO's Program C, developed this larger and more advanced satellite. The NRL launched the first Poppy satellite on 13 December of 1962, and the Poppy program completed seven missions. The NRL launched the last Poppy mission on 14 December 1971.

EVOLUTION OF POPPY

The initial Poppy mission succeeded, as did all six additional missions. The Air Force used three versions of the Thor Agena booster for Poppy: Thor Agena-D for Poppy 1, 2, 4, and 5; a Thrust-Augmented-Thor (TAT) Agena-D for Poppy 3; and the Thorad (also know as Long-Tank Thrust-Augmented Thor) Agena-D for Poppy 6 and 7.

The first Poppy missions featured a stretched spherical satellite design, initially 20 x 24 inches (at 55 pounds), which ultimately became 24 x 32 inches (at 129 pounds).

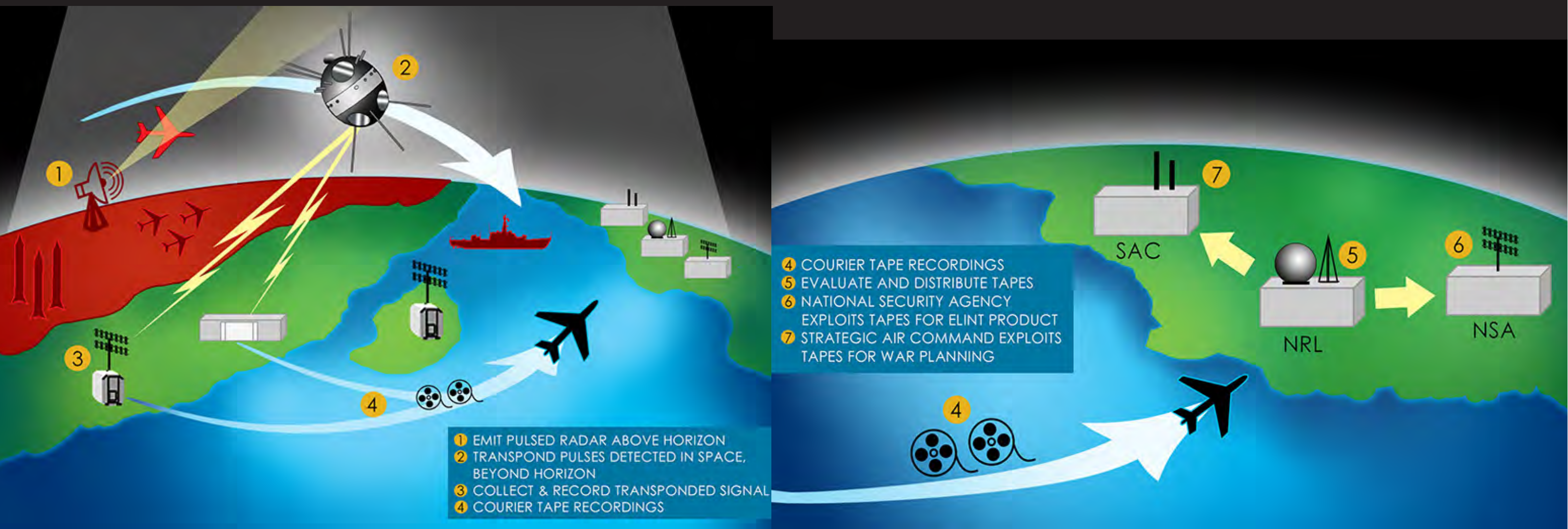
Poppy also featured a 12-sided multiface design, initially 27 x 32 inches (at 162 pounds), which ultimately became 27 x 34 inches (at 282 pounds).



Two Poppy designs—stretched sphere (left); multiface (right)

INTELLIGENCE NEED FOR SIGNALS COLLECTION

Intelligence derived from data that Poppy collected went to support a wide range of intelligence applications. It provided cues to the location and capabilities of radar sites within the Soviet Union; it provided SAC with characteristics and locations of air defense equipment to support building the U.S. Single Integrated Operations Plan (SIOP)13; it provided ocean



surveillance information to Navy operational commanders; and, with data from the Corona imaging reconnaissance satellite, it provided a more complete picture of the Soviet military threat. We can credit these systems with helping the U.S. win the Cold War. At the same time they extended their impact into the future, as they laid the foundation for future national reconnaissance capabilities. The NRO's 21st-century Sigint reconnaissance capabilities grew out of GRAB and Poppy innovations in the 1960s and 1970s.

From the relatively safe distance of 600 miles above the Earth, Poppy intercepted Elint signals from radar sites throughout the Soviet Union. The threat of Soviet hostile action limited U.S. airborne and ground-based platforms to collecting signals from radar sites to only 200 miles inside Soviet territory.

ADVANCEMENTS

Poppy added ocean surveillance capabilities. During 1965-67, Program C phased out the earlier receiving and control huts used for GRAB; the program also upgraded data quality by installing equipment in buildings provided by host installations. This upgrade also augmented manual analysis in the field.

POPPY

1962 - 1977

Successful Missions: 7

Size: 20X24(stretched spherical)
24X32 (multifaced)

POPPY MISSIONS

LAUNCHES

Poppy 1	13 Dec 1962	THOR/AGENA D
Poppy 2	15 June 1963	THOR/AGENA D
Poppy 3	11 Jan 1964	THRUST-AUGMENTED-THOR/AGENA D
Poppy 4	9 March 1965	THOR/AGENA D
Poppy 5	31 May 1967	THOR/AGENA D
Poppy 6	30 Sept 1969	THORAD/AGENA D
Poppy 7	14 Dec 1971	THORAD/AGENA D

ABM SYSTEM TESTING DETECTION

Nixon and Brezhnev Sign The Anti-Ballistic Missile Treaty.

ABM Testing Facility
Sary Shagan- Soviet Union

FROM A HOT TO COLD WAR

The United States' nuclear bombing and destruction of Hiroshima and Nagasaki in Japan brought to close a global hot war, yet started a global cold war. The United States underestimated the pace with which nuclear weapons would be developed by the Soviet Union. In order to assure that the Soviet Union would be unsuccessful in carrying out a surprise nuclear weapons attack, the U.S. invested heavily in a number of weapons systems. One of those was an anti-ballistic missile (ABM) system designed to shoot down incoming intercontinental missiles from the USSR. The USSR, unsurprisingly, countered with development of their own ABM system, raising the potential for a successful nuclear strike against the United States. Consequently, the U.S. turned to national reconnaissance systems to understand the development and deployment of Soviet ABM systems and to increase the odds of preventing the global Cold War from turning hot.

NUCLEAR WEAPONS SYSTEMS DEVELOPMENT AND DETECTION

After the United States' Manhattan nuclear weapons development program successfully produced the bombs that destroyed Hiroshima and Nagasaki, nascent U.S. intelligence reporting concluded the Soviet Union was unlikely to develop a successful nuclear weapon before 1953, but could possibly develop one as early as 1950. The United States was surprised when their nuclear detection program confirmed the Soviets' first successful atomic weapon test, which occurred on 3 September 1949. The Soviet Union was also surprised 20 days later when President Truman announced to the world the Soviets' successful test, believing they could hide a successful nuclear weapons test.

The United States had wisely decided to develop a system for detecting foreign nuclear detonations, growing out of their own research efforts to identify and track nuclear fallout from their own weapons testing. In 1947, then Army Chief of Staff, General Dwight D. Eisenhower, designated the Army Air Corps—soon to be the U.S. Air Force—to develop a system to pick up indications of nuclear fallout at high altitudes. Shortly after the successful Soviet test, U.S. military aircraft captured nuclear fallout through this detection system, operated by U.S. Air Force. Early in the Cold War, the United States understood the importance and difficulty of developing systems to track the development of Soviet nuclear weapons in a highly closed society.

U.S. ABM DEVELOPMENT

At the same time as developing nuclear testing detection capability, the U.S. also engaged in the development of a weapons system that could be used to destroy nuclear weapons before they reached the U.S., eventually known as an anti-ballistic missile system. In 1950, the U.S. began testing the Nike Ajax, designed to launch from the ground with command guidance for tracking incoming aircraft for intercept and destruction. This critical capability, would allow the U.S. to destroy the most likely means of delivering a nuclear weapon in the early days of the Cold War. The Ajax system was followed by the Nike Hercules system that also used command guidance, but could intercept targets 150,000 feet away—three times the distance of the Ajax system.

By the mid-1950s, the United States faced an emerging threat from newly developed Soviet intercontinental ballistic missiles (ICBMs). During 1955 and 1956, the U.S. carried out intensive ABM technology studies. The studies led the U.S. to award a contract to Western Electric, Bell Labs, and Douglas Aircraft to develop a new ABM system known as Nike Zeus to intercept ICBMs. Following the Soviet Union's successful launch of their Sputnik satellite in October 1957, the program took on new urgency. Nike Zeus utilized radar to identify and track ICBMs and used computers to assign specific ABM batteries to strike against targeted ICBMs. Before Nike Zeus could be deployed, the U.S. determined through system tests and studies that the system could not effectively counter a Soviet attack using multiple ICBMs and decoys.

The U.S. remained resolved in developing an ABM system and began development of what would be known as the Safeguard system by the time Richard Nixon became president in 1969. The new system utilized a phased array radar. The Safeguard system incorporated fixed antennas with electronic beam steering at U.S. ABM sites. Two different ABMs were developed under the program. Spartan missiles were to be launched first for farther out ICBM interception, and Sprint ABMs would be used for ICBMs that were closer to their intended targets. Under the Nixon administration, the system was intended to protect offensive nuclear weapons sites in Montana and North Dakota.

SOVIET AND CHINESE ABM SYSTEM DEVELOPMENT

Beginning in the late 1950s, the Soviets began testing missiles that could intercept weapons delivery vehicles at their missile testing facility at Sary Shagan. In 1961, they successfully intercepted one of their own missiles launched from their facility at Kapustin Yar.

By 1962, the Soviets began constructing their own ABM system to intercept U.S. ICBMs in the event of a nuclear attack. The system depended on radar facilities to identify incoming targets and track those targets for attack by Soviet ABMs. The U.S. nicknamed the radar facilities as "Dog House" because of their A-frame shape. Those facilities were latter supplemented by "Cat House" radar facilities, as well as "Hen House" radar facilities around the periphery of the Soviet Union to provide early warning. The ABM system was developed to protect Moscow against nuclear attack.

Like the U.S., the Soviets developed ABMs that were intended to intercept missiles at long range and short range—the Galosh and Gazelle missiles respectively. Also like the U.S., the Soviet ABM system could not handle the large number of targets that would likely be launched in a full-scale nuclear exchange. The rapid proliferation of nuclear warheads exceeded advancements in ABM system capabilities.

Prompted by U.S. and Soviet nuclear weapons and ABM systems development, in 1964, the People's Republic of China (PRC) initiated their own ABM system. They eventually undertook development and testing of the Fanji ABMs. The Chinese also developed ground radar tracking stations for early warning of a nuclear attack. In addition, the PRC undertook development of the XianFeng anti-missile gun. Although ambitious, these programs were canceled by 1977 after the death of PRC Chairman Mao Tse Tung.

ANTI-BALLISTIC MISSILE TREATY

The United States and the Soviet Union both recognized the limitations of ABM systems as rapid development of nuclear weapons systems occurred on both sides. The pace was amplified by the development of multiple nuclear warheads that could be launched using a single ICBM. As a result of these realities, in 1972 President Nixon and Soviet Premier Brezhnev signed an anti-ballistic missile treaty. The treaty allowed both sides to protect one ABM site and one site for weapons system command and control. As a consequence, the U.S. dismantled its Montana ABM missile system site and later decided not to deploy an ABM system to defend Washington, D.C.

This left only the site in North Dakota where U.S. ABM system development continued. The site became operational in 1974, but the U.S. Congress rejected the utility of an ABM system and discontinued funding the North Dakota site. It closed in 1976.

The Soviet Union continued to build and maintain an ABM system to defend Moscow against attack. ABM system development continued after the Soviet Union collapsed in 1991.

THE ROLE OF RECONNAISSANCE SATELLITES IN ABM MONITORING

One critical element of any arms control treaty is the ability of each party of the treaty to verify the other parties' compliance. Such was the case for the U.S. and the USSR with respect to the ABM treaty. The treaty specified a new term, "National Technical Means," to be used to verify treaty compliance. When the treaty was signed in 1972, the United States' reconnaissance satellites developed and operated by the NRO remained highly classified. For the United States, "National Technical Means" meant NRO satellites. It would not be until 1978 that the U.S. acknowledged the existence of reconnaissance satellites and until 1992 that the U.S. would acknowledge the existence of the NRO. Despite the lack of public acknowledgment, the highly innovative and capable NRO reconnaissance satellite architecture served as the primary means for ABM treaty verification, as well as assessments of the threat posed by Soviet ABM system development from the early stages of their development.

GEOLOCATION FROM SPACE

FOUNDATION FOR GLOBAL POSITIONING SYSTEM


GPS - NAVSTAR

GEOLOCATION IN THE 21ST CENTURY

In the 21st century, satellite geolocation is ubiquitous, woven into the fabric of everyday life for billions of people worldwide. Individuals have apps on their phones, tablets, watches, and in their cars, capable of determining their precise position on the Earth, of providing a directed route to a selected destination, even warning of upcoming obstacles like heavy traffic or road construction. What has made this possible is the Global Positioning System (GPS), a constellation of more than 30 satellites, together with comparable systems in Europe and Asia. Given its widespread adoption and everyday influence, it can be easy to forget that this technological innovation is a very recent phenomenon that made obsolete the natural observation methods humans had used for centuries. Where once ship captains used stars in the sky and dead reckoning techniques to calculate where they were at sea, the modern traveler links to human-made celestial bodies—orbiting satellites with ultra-precise atomic clocks—to obtain much more accurate and reliable location information. Although most knowledgeable users today know that this technology was once the exclusive province of military and intelligence organizations, many remain unaware of the role the National Reconnaissance Office and other organizations played in developing it. The story of using space-based systems for geolocation is a great example of how American technological innovations originally pursued for supporting military forewarning and national security policymaking, were later transferred to the private sector as the foundation for innumerable, related innovations, e.g., self-driving cars or steps-counting fitness bands and myriad other civilian and commercial applications.

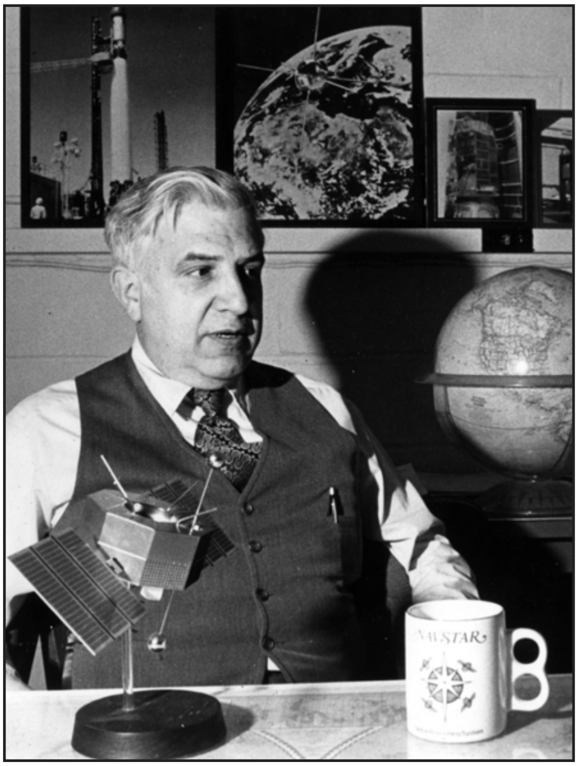
During the Cold War, the Soviet Union's obsession with secrecy and systemic suppression of even the most trivial details about life behind the Iron Curtain, made extremely challenging the gathering of intelligence by traditional means. Soviet security services concealed progress of their country's post-WWII nuclear weapons program—and penetration by its spies—so well that their first successful atomic detonation in 1949 shocked Western intelligence experts who had forecast that the USSR was still years away from obtaining "the bomb." The arms race that ensued—four years later to the month, the Soviets countered another American weapons development success, the testing of a hydrogen bomb, by exploding their own powerful fusion weapon—produced further uncertainty and instability. Knowing the Soviets' military intentions and capabilities, particularly its strategic missile numbers and strength, became a paramount concern. Were conflict to break out, the U.S. military response needed to be immediate, reliable, and, above all, accurate, which required knowing where and what to target for annihilation. Unfortunately, given the lack of intelligence in the 1950s, and the vast interior of the USSR, it was difficult to know even where to begin to look. To provide military commands and national policymakers better information, the U.S. Intelligence Community proposed overhead reconnaissance missions, first through conducting aerial overflights of denied territory, and later by launching and operating satellites. Beginning in 1956, U-2 high-altitude reconnaissance aircraft missions began to pull back the curtain, revealing previously unknown military installations, missile launch facilities, and dispelling the myth of the "bomber gap." But it would be the advent of space-based systems that would enable the U.S. to really penetrate Soviet secrecy and collect the vital information that removed uncertainty, lessened tensions, and allowed the Cold War to remain "cold." In time, satellites would also provide military leaders with the capability to geolocate enemy combatants and weapons systems to perform precision air and missile strikes.

Ironically, the earliest satellite geolocation method may have been conceptualized partly in response to the Soviet launch of Sputnik-1. In tracking the tiny satellite's radio signals, scientists at Johns Hopkins' Applied Physics Laboratory noted that signal frequency increased as the vehicle approached and decreased as it moved farther away, an illustration of the Doppler Effect. The scientists extrapolated that a satellite could be tracked from the ground by measuring the frequency of emitted radio signals, and conversely, one could determine the location of the unit receiving that signal by knowing its distance from the satellite. This realization led to the first operational, satellite-based, geo-positioning system, the U.S. Navy's Transit program, begun in 1958. Transit was not a true navigation system, but instead a positioning system for fixed objects, initially designed to meet the Navy's need for accurately locating Polaris submarines at sea by updating shipboard inertial navigation systems. When Transit became fully operational in January 1965, submarine or ship navigators could measure the Doppler shift in a Transit satellite's radio transmissions during the 15 minutes it took to travel from horizon to horizon to calculate their sub or shipboard receiver's position on Earth. In 1967, the Transit system was made available as a broad ocean navigation system for civilian ships, by which time the NRO and Department of Defense had further advanced space-based geolocation on other programs.

On 22 June 1960, the Naval Research Laboratory, site of what became NRO Program C, put into orbit the U.S.'s first successful reconnaissance satellite, GRAB, launched as a "piggybacked" payload aboard the Transit 2A satellite. Throughout the 1960s and into the early 1970s, the NRO's low-earth orbiting, signals intelligence (Sigint) collecting satellites GRAB, and the even more successful follow-on system Poppy, used high gain antennas to intercept signal pulses from Soviet radar equipment and then transponded corresponding signals to receiving huts. Once processed, the signals provided analysts cues to the location, strength, and number of radar sets trying to detect oncoming U.S. strategic bombers. Although not accurate by GPS standards, the geolocation method used with early Sigint satellites was geometric reconstruction using the direction of arrival of a signal at a single intercepting satellite whose location and orientation was accurately known. Later the NRO would discover how to use a different method to achieve much more precise location information. In addition to providing Strategic Air Command critical flight route data to support building the Single Integrated Operations Plan, Poppy satellites provided ocean surveillance info to Navy operations commanders, and in combo with imagery satellites, gave a more complete picture of the Soviet military threat.

As the NRO satellite constellation grew and evolved over the succeeding decades to comprise many longer duration mission payloads operating in multiple orbital types (e.g., low earth, geosynchronous, sun-synchronous, highly elliptical, etc.), it continued to redefine state-of-the-art in remote sensing technology in ways that exponentially increased the intelligence windfall. Pioneering NRO engineers discovered novel ways of exploiting signal externals measurements to greatly improve tracking and geolocation of missiles by reconstructing their altitude. This led to the first demonstrated geolocation capability from space using methods tried previously with aircraft, but thought to be unworkable with satellites. Precision timing was needed, and for that, the NRO employed cesium clocks, an innovation that would be critical to the success of GPS. Though it took a few years for space-based geolocation breakthroughs to be fully exploited, eventually satellite enhancements and refined techniques made measurements more accurate, and space-based geolocation remains at the forefront of a variety of intelligence applications.

Also known by its formal program name, NAVSTAR, GPS took more than two decades to mature from concept to fully operational, and the program office built upon technologies and satellite geopositioning techniques discovered and honed by NRL, NRO, and the Aerospace Corporation, to name a few. Of these contributors, the NRO Program C connection to GPS's development is least well known. As previously noted, Program C was headquartered at NRL, but it was far from the only activity there. Founded at the suggestion of Thomas Edison to create an organization to house a "repository" of technical capability, NRL began foundational work on a precise, all-weather, real-time, global navigation system independently of Aerospace's more touted efforts, and well before the consolidated NAVSTAR program. Two key NRL contributions to the GPS program were development of precision cesium and rubidium atomic clocks, which had to be improved 100 fold for use in satellites, and the use of refurbished Atlas F launch vehicles to boost the payloads into orbit. At the forefront were two brilliant engineers, Roger L. Easton, considered by many to be the “Father of GPS,” and Peter G. Wilhelm, a Pioneer of National Reconnaissance and technical director and lead engineer for 74 satellites over his 50-year career at NRL. In 1964, Easton began research and experiments to demonstrate his idea for instantaneous satellite navigation using passive ranging and a constellation of satellites containing high-precision, atomic clocks and operating in a circular orbit. Easton called his system TIMATION (time-navigation). By 1967, he was ready to prove his concept through an initial satellite launch. Here the connection to NRO Program C becomes clearer.



Roger L. Easton

Wilhelm—but not Easton—was actively working NRO satellites for Program C, and had developed the radio transmitters and receivers for GRAB. In the same year that Easton began his Timation work, NRL promoted Wilhelm to lead all of its satellite programs, including those being funded by the National Reconnaissance Program. So when the time came to launch the first two of Easton’s Timation satellites, Timation-I on 31 May 1967, and Timation-II on 30 September 1969, Wilhelm arranged to have those satellites launched—as GRAB had been—in “piggyback” mode atop NRO satellites Poppy 5 and Poppy 6. These were the first demonstrations of what became the GPS navigation concept from space, the first of four experimental satellites that Easton had developed. Even after the Air Force, along with Aerospace, established a GPS program office in 1972, it was Easton’s Navigation Technology Satellite-2 (NTS-2; the first had launched in 1974), launched in 1977, that became the first satellite in the NAVSTAR GPS.

Peter G. Wilhelm

Wilhelm’s hand can also be seen in the decision to use the Atlas booster—specially modified—for the NTS launches, rather than the more expensive Thor/Agena D combination employed for the Timation launches. Wilhelm conceived the idea of an Atlas combined with two solid rockets with no onboard guidance, which were used to transfer the satellites to GPS’s 10,000+nm orbit, a concept he called “arrow.” Wilhelm proposed this new, lower cost launch concept to Director, NRO John McLucas in 1972. Being able to affordably launch a 24-satellite constellation to become fully operational was key to gaining GPS program approvals, and the approach was used on the first 13 launches.

ICBM DEVELOPMENT DETECTION

Atlas ICBM - 1957

Corona KH-4 Image

IDEOLOGICAL DIVIDE OF THE COLD WAR

If the victorious Western allies of World War II believed that the defeat of Nazi Germany and Imperial Japan would bring about a new era of global harmony, free from conflict, in which smaller nations could exercise political autonomy, they soon discovered they were mistaken. In Europe, erstwhile ally USSR took little time reneging on most commitments pledged by Stalin at the Yalta Conference in February 1945. Germany itself would be occupied for the foreseeable future, and was divided ideologically into East and West amongst four nations as agreed, but the Soviet leader also had paid lip service to a postwar principle of allowing free elections in eastern European states liberated from Nazi forces (i.e., Czechoslovakia, Poland, Romania, Hungary, and Bulgaria). The Red Army's overwhelming presence in those countries, however, ensured that the USSR could instead facilitate the installation of puppet regimes, in effect obtaining for Moscow not simply a sphere of influence over Eastern Europe, but by the early 1950s, political domination behind an "Iron Curtain." Meanwhile in China, after decades of civil war, the Chinese communists emerged victorious in October 1949, mere weeks after the USSR had detonated an atomic bomb, ending the U.S. monopoly of nuclear weapons. Less than a year later, North Korean forces invaded South Korea, equipped with Soviet weapons and with China's encouragement. Observing all these developments, Winston Churchill entitled the last book of his Second World War memoirs Triumph and Tragedy because, he wrote, "the overwhelming victory of the Grand Alliance has failed so far to bring general peace to our anxious world."

INFORMATION GAP IN DENIED AREAS

With the nuclear arms race begun and the Cold War intensified, Western governments became increasingly uneasy about the growing military threat from the closed society of the USSR and Communist Bloc. Never mind a lack of timely, reliable data on military capabilities and intentions, the West had difficulty obtaining propaganda-free information on simple, everyday events within the Soviet sphere. The Communist countries of the 1950s erected at their borders checkpoints that were constantly patrolled by military forces. It was a world composed of single-party, totalitarian governments, whose ruthless, disciplined, and formidable security forces rigidly controlled the flow of information, and imposed suspicion and fear upon their populations to ensure their docile compliance, if not active cooperation in exposing supposed enemies of the state. This made intelligence collection through traditional human espionage in these so-called "denied areas" extremely difficult and highly dangerous. But strategic reconnaissance systems, until 1956 comprised of specially adapted camera-carrying aircraft and aerial balloons, also proved of limited value. Western leaders were left with fragmentary information, all of which seemed to indicate, at worst, warlike intentions, and at best, a Soviet strategy of destabilizing governments throughout the world to extend the Communist power base beyond Eastern Europe. The U.S. developed the innovative U-2 high-altitude, reconnaissance aircraft in just eight months after Presidential approval, and beginning on 4 July 1956, conducted periodic overflights of the interior of the Soviet Union. Although a tremendous success—U-2 imagery conclusively refuted intelligence estimates of a significant Soviet advantage in long-range bomber production—the U-2 program highlighted inherent limitations even with high-altitude aircraft reconnaissance: relatively infrequent missions, narrow imaging passes that excluded large swaths of territory, and vulnerability to countermeasures. On 1 May 1960, Francis Gary Powers, piloting the U.S.'s 24th mission over the USSR, was shot down by surface-to-air missiles, and President Eisenhower terminated all future overflights of the Soviet Union. A new reconnaissance capability was needed, and, fortunately, one was not long in coming.

A NEW KIND OF INTELLIGENCE PROVIDES HIGH CONFIDENCE UNDERSTANDING

Even while the U-2 flights were ongoing, the Soviet Union had upstaged the U.S. on two space-related developments: intercontinental ballistic missiles and space satellites. When America tested its Atlas ICBM in July 1957, the missile only rose about 5,000 feet before plunging back to Earth. A month later, the Soviets announced that they had successfully tested an ICBM, although the U.S. could not confirm the story's veracity. On 4 October 1957, the Soviets removed all doubt by launching the first man-made satellite, Sputnik 1, which the world tracked as it orbited the Earth. Troubling to many was the realization that if the Soviets could develop ICBMs powerful enough to launch an object into space, they could potentially equip similar missiles with nuclear warheads to launch a devastating attack. And because of the lack of solid evidence to the contrary, these fears received outsized attention. Thus, the 1960 presidential election became, in part, a referendum on concerns about the Soviets outpacing the U.S. in strategic nuclear capabilities — this time the production of nuclear missiles rather than bombers. Democrat candidate John F. Kennedy assailed the Eisenhower administration, including then sitting Vice-President and opposing Republican candidate Richard Nixon, for its failure to prevent this "missile gap" from developing. What the candidates did not know when the campaign began—and could not reveal even after they became aware of it—was that the U.S. had successfully developed a new capability that eventually would provide high confidence understanding of Soviet ICBM development and completely transform national reconnaissance: signals and imagery satellites.

CORONA AND SUCCESSORS' CONTRIBUTION TO ICBM DETECTION AND TREATY VERIFICATION

The launch of the GRAB signals intelligence satellite on 22 June 1960, followed by the launch of the Corona photoreconnaissance satellite on 18 August 1960, revolutionized intelligence collection of denied areas. Going forward, U.S. policymakers could at last be confident of both the accuracy and scope of intelligence assessments of Soviet strategic capabilities, not least because of an improved ability of "negation," or verifying the absence of activity. CIA and Air Force elements, after 6 September 1961 as components of the NRO, would operate Corona satellites, with steadily improving camera technology and collection capabilities, for 145 missions spanning nearly 12 years. The system's broad-area, panoramic imagery made possible the identification of all Soviet medium-range, intermediate-range, and ICBM launching complexes, definitively dispelling fears that the U.S. lagged behind in missile production. After June 1963, Corona would conduct search missions in conjunction with the Gambit imagery satellite system's high-resolution, narrow-field-of-view mission to provide close-look information. Through repeated coverage of areas of concern and a coordinated search process that involved close cooperation among satellite operational units, photo interpreters, and all-source analysis components, the NRO programs enabled compilation of a huge database of newly identified installations and activities: ICBM sites, air defense sites, nuclear development and test facilities, shipyards, airfields, communication sites, military bases, manufacturing and agricultural activity, etc. By the middle of the 1960s, the U.S. and its allies were assured that they knew the scale and pace of Soviet ICBM deployment within narrow limits. Past areas of uncertainty, such as "where" and "how many," no longer caused concern and were replaced by questions of detailed characteristics for delivery systems. The dramatic reduction in the number of intelligence surprises paved the way for the initiation of strategic arms limitation talks between Washington and Moscow, for which area-coverage imagery provided by Corona (and starting in June 1971 by Corona's successor, Hexagon) would be indispensable for monitoring resulting treaty provisions. Indeed, verification of compliance through use of imagery satellite systems—termed "national technical means" to obscure specifics about still-classified programs—provided leaders of both countries with the confidence that permitted them to sign the Strategic Arms Limitation Treaty on 26 May 1972.

SHIP TRACKING (OCEAN SURVEILLANCE)

The earliest U.S. reconnaissance satellites began operation when there were many strategic intelligence gaps, and their express purpose was to provide American leadership visual and electronic access to the vast landmass of the USSR, the major Cold War adversary. Space-based photoreconnaissance and signals interception missions quickly proved adept at acquiring the data to find and locate objects of interest, catalogue significant activities, and confirm the absence of activity. By the mid-1960s, satellite reconnaissance had reduced the number of intelligence surprises, and the U.S. and Western Allies were becoming increasingly confident that, for example, they knew the scale and pace of Soviet ballistic missile deployment within narrow limits. But a new threat was emerging: the USSR had begun to build up a large and formidable navy. From its Baltic and Black Sea shipyards, the Soviet Union accelerated development and production of combatant and auxiliary ships, including new cruisers, frigates, and destroyers armed with guided missiles; cruisers carrying missile-equipped helicopters; and nuclear submarines armed with ballistic missiles. This rising world-class fleet was soon deployed around the globe, particularly in waters adjacent to non-aligned nations. Although the U.S. Navy monitored its movements as closely as it dared from its own surface vessels while carefully avoiding causing a diplomatic incident, reconnaissance satellites offered far greater potential for closing this new intelligence gap through collecting imagery and signals to establish a database on the USSR naval order of battle and its activities. It was only a matter of time before ocean surveillance—i.e., tracking ships—became a satellite collection mission requirement.

1. **Emit pulsed radar above horizon**
2. **Transpond pulses detected in space, beyond horizon**
3. **Collect & Record transponded signal**
4. **Courier tape recordings**

The U.S. Intelligence Board (USIB) issued formally documented satellite mission requirements, which in the formative years of space-based reconnaissance tended to reflect the needs of whichever military or intelligence organization would be using the information. For example, Air Force Strategic Air Command wanted details on Soviet targets, data on radars and anti-aircraft weapons, and exact locations of Soviet defensive installations, so it could plan aircraft penetration routes. The CIA was additionally interested in, and tasked to produce, intelligence estimates on Soviet technology, military numbers and capabilities, and economic indicators. As more was learned of the USSR's naval buildup, the U.S. Navy wanted to determine the threat from Soviet surface ships and submarines. The Soviet navy had doubled its activity in the Mediterranean Sea in 1967, and a Navy Space Program Review concluded that the Department of the Navy must move boldly to translate space policy to fleet needs. This had not been a priority until then, and more than a decade into the Space Age, the only operational U.S. satellite-based system that directly supported its fleet was the Navy Navigation Satellite System, more popularly known as Transit. But Transit was older, limited technology used as a positioning system for fixed objects, when the ship tracking problem required a system capable of detecting and tracking mobile threat radars. Fortunately, NRO systems' advancements to satellite collection, geo-positioning capabilities, and increased sensitivity now enabled space mission planners to consider incorporating ship tracking requirements, which could provide insight into Soviet military intentions, as well as their economic and diplomatic activities. Rear Admiral Leonard, who commanded a carrier division and was interested in tracking missile-equipped Soviet ships at sea, submitted a request through the Chief of Naval Operations for "the conduct of tests by the NRO to evaluate satellite use for passive detection, classification and localization of ships at sea."

One prime candidate to perform this mission was the NRO's electronic intelligence satellite system, Poppy,* developed by Program C at the Naval Research Laboratory and operated by the NRO from 1962 until the late 1970s. Poppy used high-gain antennas to intercept signal pulses from Soviet radar equipment and then transponded corresponding signals to receiving huts. Once processed, the signals provided analysts cues to the location, strength, and number of radar sets the Soviets could employ to detect oncoming U.S. strategic bombers. With early Sigint satellites like GRAB and Poppy, NRO engineers initially used a geolocation method based on geometric reconstruction. But they later discovered novel ways of exploiting signal externals measurements to greatly improve tracking and geolocation of missiles by reconstructing their altitude, leading to the first demonstrated geolocation capability from space.

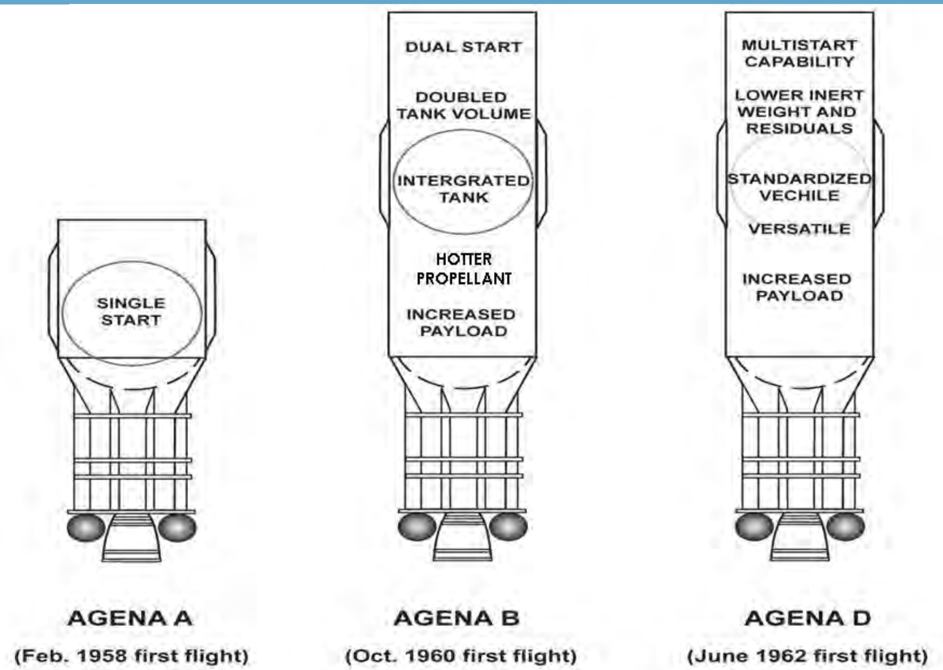
As the NRO evolved the system through successive enhancements, low-earth-orbiting Poppy proved best at intercepting ship-based radars, which were sometimes on for only a few fleeting moments because of the deception tactics used by Soviet ship captains to avoid detection. In 1970, the USIB added electronic-order-of-battle production and ocean surveillance to Poppy mission guidance. With consequent upgrades to receiving stations, the Poppy program became an interim ocean surveillance system, while continuing also to provide Strategic Air Command critical flight route data to support building the Single Integrated Operations Plan and performing anti-ballistic missile search and general search missions to give Navy operations commanders and Intelligence Community decision-makers a more complete picture of the Soviet military threat. The success of the Poppy system also paved the way for the NRO, in conjunction with its mission partner, the National Security Agency, and the Navy, to sponsor development of a more advanced successor system dedicated to monitoring the threats manifested by an expanding, worldwide, blue-water Soviet Navy. With the establishment of offices for Tactical Exploitation for National Capabilities (TENCAP) in the military services, the NRO was able to provide not only direct support regarding enemy warships, merchant ships, and land-based emitters to the fleet, but also operational Elint support to the Army and Air Force.

* The Poppy system had evolved from GRAB, the very first national reconnaissance satellite, which on 22 June 1960 launched as a "piggybacked" payload aboard the Transit 2A satellite.

INNOVATIONS

SPACE ENTERPRISE

AGENA



FOUNDATION OF SPACE RECONNAISSANCE

In 1946, the U.S. Army Air Force placed a requirement for Project RAND to study the technical feasibility of orbiting artificial satellites, which eventually became the Air Force's Advanced Reconnaissance System or Weapon System 117L (WS-117L). After numerous bids, on 29 October 1956, Lockheed Aircraft Corporation (which had teamed with Eastman-Kodak) was awarded the prime contract for the liquid-propellant Agena booster-satellite developed for the WS-117L program. The contract had three operational components: Samos (named after a Greek Island), was the pioneer version that was a near real-time photographic reconnaissance system; Ferret, an advanced version, was an electronic signals collector; and Midas, a surveillance version, was an infrared system that was capable of serving as an early warning missile system by detecting heat from missile launches.

An integral part of each of these systems was a general purpose vehicle that provided two critical functions. First, the vehicle served as a second-stage booster to place a variety of probe and satellite payloads into stable orbits after the Atlas Intercontinental Ballistic Missile first-stage boosters burned out. Second, once in orbit, the upper stage of the Agena vehicle served as the satellite control section by supporting the electrical power, three-axis attitude control for stability and pointing, and communications for both command and control of the payload functions and downlink telemetry for both satellite health and mission data.

SAMOS AND AGENA

In each of its three Samos missions, the Agena vehicle was required to support payloads with varying requirements. For example, the Samos' imaging payload could point off-axis to a limited degree to photograph targets that were not directly below the satellite, but to the outer periphery. Midas' infrared scanners rotated around the pointing axis to view the horizon looking for missile launches. Ferret was slightly different in that it was a signals collection antennae attached to the Samos on the front of the satellite to have an unobstructed view of the Earth below.

Samos finally launched on 11 October 1960, but the first launch failed to reach orbit. Later launches proved there was an issue with transmission capability that limited the downlink speed, which made this ineffective as an operational reconnaissance system. Midas first launched its two developmental missions in 1960 from Cape Canaveral while waiting on the completion of launch pads at Vandenberg Air Force Base in California.

Discoverer 14 Agena Spacecraft

Lunar Orbiter Launch
Agena D
10 Aug 1966

CORONA AND AGENA

As the program schedule for WS-117L slipped, there was a need for an interim photograph system using the Agena with a smaller Thor Intermediate Range Ballistic Missile as the first stage booster. Lockheed urged the adaptation of the WS-117L upper stage to the Thor missile as the first step in the program acceleration. This version was initially powered by the Bell XRM-81 rocket engine, originally designed for a B-58 Hustler bomber program, hence the name Thor-Hustler. Later this upper stage was called the Agena, and it was used for Discoverer, the cover name for the Corona program.

Unlike WS-117L, Corona required the Agena vehicle to fly with its long axis parallel to the ground so that the panoramic camera system could image a swath from one side of the flight path to the other. Since it also had a film re-entry capsule that had to be ejected from the Agena, the vehicle would maneuver to a 60 degree downward position to provide the proper re-entry sequence and recovery. The Agena was equipped with body-mounted roll and pitch position gyroscopes updated by the horizon sensor. The attitude control system would allow the camera to point accurately and have low roll and pitch blur rates needed for the Itek camera to deliver a resolution of about 20 feet. The Corona systems had to pass over the Soviet Union at latitudes higher than could be covered by launches from Cape Canaveral in Florida. The need for polar launches, greater security, and frequent launches to test new ballistic missile designs led to the establishment of Corona launch platforms at Vandenberg in California.

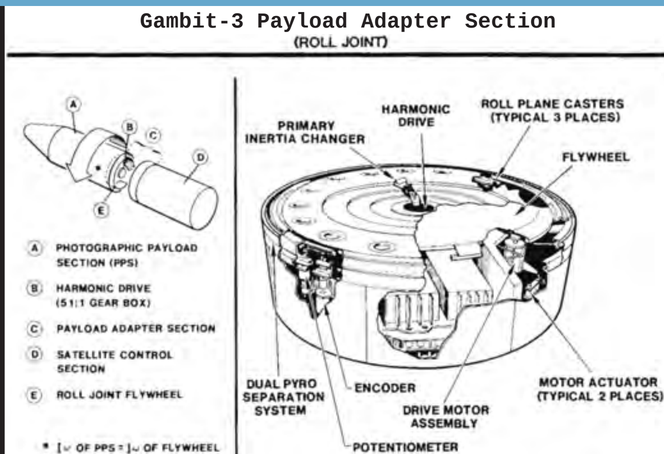
GAMBIT AND AGENA

NRO developed the Gambit satellite to provide high-resolution pointed target imagery. The Gambit-1 was designed to fly on the Atlas Agena booster. Its first flight was on July 1963, and there was a total of 38 missions. However Gambit-3, or Gambit-cubed, was flown on the Titan booster because it required a greater lift capability than the Atlas was able to provide.

Over the 28 years and 362 missions of the Agena program between 1959 and 1987, there were three basic models of the Agena vehicle flown called Agena A, B, and D. The Agena vehicle also provided other support to civil space programs including NASA. Programs like Ranger provided images of the lunar surface, and Mariner was a series of interplanetary spacecraft to investigate Mars, Venus, and Mercury. Gemini Agena Target Vehicles launched between October 1965 and November 1966 to develop and practice space rendezvous and docking techniques. The last NASA Agena flight was Nimbus 4 in 1970, and the last Agena flight was in 1987.

CONTROL MOMENT GYROSCOPES


Dirks




Hexagon Panoramic Camera Image

The groundbreaking technical achievements of the NRO's early film-return photoreconnaissance satellites – Corona, Gambit, and Hexagon – and their imagery collection were major intelligence contributors that ensured America's national security during the Cold War. However, the distribution of imagery from these satellites to analysts could take several weeks. There were also times when film-return satellites were not in orbit, and the satellites were limited in the ability to image ample intelligence targets on a daily basis. These limitations revealed a potential threat to U.S. security and demonstrated the need for an imagery satellite that could deliver intelligence in near real-time (NRT), be in orbit continuously, and image intelligence targets daily.

SATELLITE STABILITY AND NEAR REAL-TIME IMAGERY

Exploration of an NRT imagery satellite began in the early 1960s. In 1963, the CIA began funding Zoster (later renamed Zaman and then Kennen) program studies, led by Leslie Dirks, considered the father of near real-time satellites. These studies focused on the development of an electro-optical imaging (EOI) NRT system. By 1968, Dirks' team had identified a number of requirements for potential NRT satellites, which were compiled in the Application of Electro-Optical Technology to Satellite Reconnaissance study, known as "Dirks' Blue Book." It was this study that identified Control Moment Gyroscopes (CMGs) for use in the attitude control system* of NRT satellites. The attitude control would allow for the maneuvering of an NRT satellite that would need to orbit continuously and image select intelligence targets daily.

President Nixon approved the Central Intelligence Agency to begin development of the Kennen NRT satellite system on 23 September 1971.

Kennen's acquisition of intelligence targets differed from earlier film-return satellites. Gambit-3 had a roll-joint, allowing limited side-to-side imaging, while Hexagon had panoramic cameras and did not need to roll. Film-return satellites controlled attitude by either firing low-precision, life-limited, liquid-fueled reaction control thrusters or utilizing agility-limited reaction wheel assemblies. Because of their low earth orbits, film-return satellites required frequent orbit adjustments to prevent prematurely re-entering Earth's atmosphere before the complete payload had been used. These orbit adjustments consumed large amounts of propellant, which had to be carried as part of the launch vehicle. These consumables came at the expense of film payloads, and they sometimes limited days in orbit. As there had not been a maneuvering spacecraft of the anticipated size of Kennen with a life span of more than a year, CMGs would provide the attitude control that would enable Kennen's success.

DEVELOPMENT OF CONTROL MOMENT GYROSCOPES

The NRO chose an industrial partner to develop Kennen's CMGs. The launch configuration of the first Kennen satellite used six individual CMGs, allowing the satellite maximum maneuverability and the ability to point in any direction at any intelligence target. Developing the CMG required precision design in electro-magnetics, high-speed bearings, lubrications, exquisite balancing, and advanced control

*Attitude is stabilized by yaw (nose left to right movement), pitch (nose up and down movement), and roll (rotation left and right of the nose).

algorithms that pushed the capabilities of existing onboard spacecraft computers. Early Kennen missions using CMGs were not without problems. The components inside these devices spin at considerable speed, so minor imperfections would cause catastrophic failure to a spacecraft. Even with precise balance, CMGs are one of the largest sources of vibration on spacecraft and, left unchecked, would interfere with payload operations. An NRO Pioneer developed a novel and groundbreaking vibration isolation technology to lessen CMG vibration and reduce the impact on payload performance. Several NRO programs have used this technology to isolate payloads from a variety of disturbance sources.

The CMGs provided the innovative technology that integrated the best of previous capabilities to develop larger, more agile satellites with improved pointing performance and longer mission life. These highly complex electro-mechanical systems enabled NRO satellites to accomplish their essential missions for national security from the 1970s into the 21st century.

CUBESATS

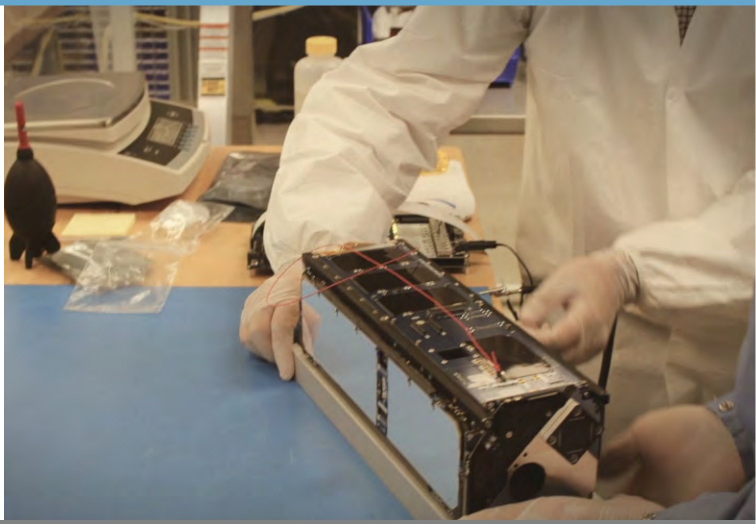
When U.S. satellite programs began in the late 1950s, satellites always started small due to the limited launch capacity of rockets used to carry the satellites into orbit. The world's first reconnaissance satellite, the Galactic Radiation and Background, an electronic intelligence satellite launched in June 1960, weighed a mere 55 pounds. As U.S. launcher technology advanced and became capable of carrying larger and heavy payloads, engineers began creating more capable satellites, which naturally became bigger and heavier. By 1971, the NRO launched the Hexagon film-return satellite, which was as large as a locomotive and weighed approximately 16,000 pounds. But as satellites got larger and more capable, they also naturally became more expensive and took longer to replace. As the nation's satellite constellation matured, it became evident that there was a need for smaller satellites to compliment the larger ones being placed in orbit, both as a time and cost savings measure and also as a survivability measure.

RIDE ALONGS

In the 1980s, the NRO began experimenting in the utility of smaller satellites. By the 1980s, interest grew in small satellites. The NRO began experimenting in the utility of smaller satellites. NASA too renewed their interest in small satellite launch efforts. The agency created its Gateway Special Program (GAS), a Space Shuttle rideshare program available for scientific and commercial use and open to educational institutions and business interest (foreign and domestic). These small payloads weighed less than 200 pounds and traveled on a space-available basis.

In the 2000s, NRO used small satellites for testing the viability of new technologies in space environments. These satellites could go from the planning stage to launch quickly and at a great cost savings because of their reduced size and weight. Rapid Pathfinder and the CubeSat program are two examples of small satellite technology pioneered by NRO's Advanced Systems & Technology Directorate (AS&T).

Rapid Pathfinder was an experimental technology testbed spacecraft developed by AS&T that launched on NROL-66 from Vandenberg Air Force Base on 6 February 2011 aboard a Minotaur 1 launch vehicle. Rapid Pathfinder's mission was to validate new research and development technologies and to demonstrate that the NRO could launch advanced technologies quickly and at a reduced cost. It was less expensive and smaller than most satellite vehicles, and it carried two advanced technology payloads. The AS&T brought Rapid Pathfinder from design to launch in just two years.



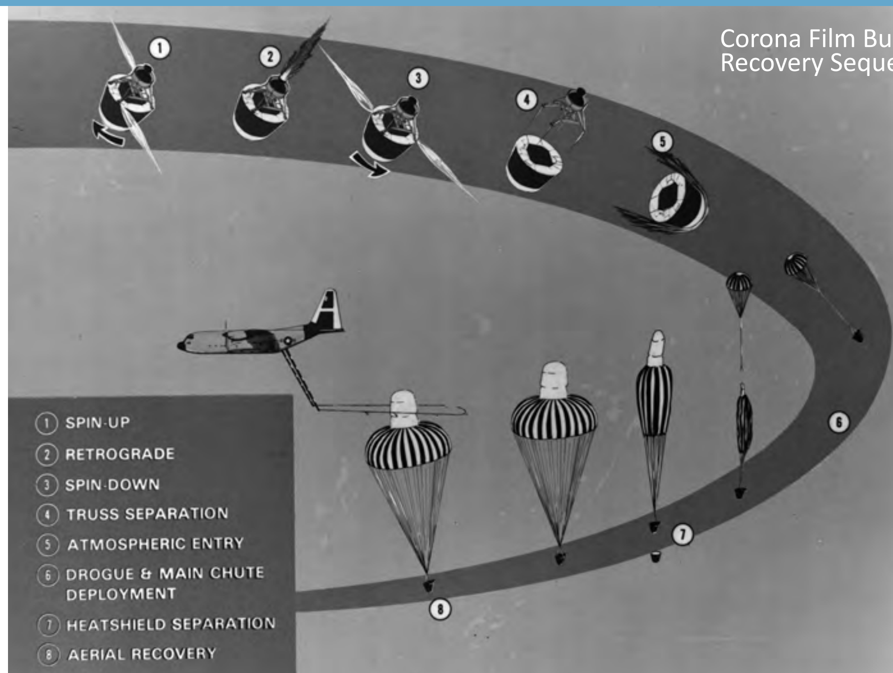
SMALL SATELLITES

CubeSats are nano-satellites developed, launched, and controlled at a fraction of the cost of a typical operating platform. CubeSats typically weigh between one and five kilograms. They are beneficial in reducing the risk of larger programs because of their low cost and rapid development cycle. California Polytechnic State University (Cal Poly) and Stanford University designed and developed the CubeSat concept in 1999. The first NRO CubeSat rideshare, OUTSat (Operationally Unique Technologies Satellite), took place in 2012 onboard NROL-36.

The NRO, NASA, and other government agencies recognize the utility of CubeSats and engage universities, service academies, laboratories, and industry to advance the state of practice. These small satellites are an important pioneering research effort that provide early evaluation of new technologies and test their survivability and performance in space environments. Today, NRO can easily test new technologies for a small fraction of the time and cost of previous development programs. Additionally, by teaming with other researchers and organizations, the NRO can provide rideshare on its launches and benefit from the cost savings and technology sharing with these various "hitchhikers."

FILM RETURN


Genetrix Balloon



Corona Film Bucket Recovery Sequence

LAYING THE FOUNDATION

When people are asked about the first film-based intelligence satellite, they invariably think of the Corona program, and rightly so. However, that program would not have been as successful if not for the experience gained from an earlier film-return reconnaissance effort called Genetrix.

On 10 January 1956, the Air Force launched the first of what would eventually be 516 high-altitude balloons released from Europe and Turkey that were designed to sail over Eastern Europe, the Soviet Union, and China, taking pictures at intervals along the way. The balloons were then caught in midair, after they had passed hostile territory and floated out over the Pacific Ocean, by Air Force crews flying C-119 aircraft. While simple in concept, the planners failed to take into consideration one small detail—Mother Nature. After launch, the balloons were at the whim of high-altitude wind currents, which were not well understood in 1956. Most flew too far south to be of use, and many blew far off course and were lost. After a couple weeks, Soviet fighter pilots realized that at dawn, the balloons had floated to a lower altitude due to the cooler night air and could be shot down. Of the 516 balloons launched, only 46 were recovered, and only 34 succeeded in returning useful imagery. The program was cancelled by President Eisenhower after only a month because of Soviet protests. However, the mid-air recovery experience gained by the Air Force flight crews in training and actual operations proved invaluable when they were recalled two years later for the Corona program.

CORONA

President Eisenhower approved the Corona program in February 1958. The design called for a film-based camera system to be launched into orbit, to take pictures as it passed over denied areas, to collect the film in a bucket at the tip of the satellite, and when all of the film had been exposed, to release the bucket back into the Earth's atmosphere to be caught midair as it descended toward the ocean. All nine pilots who had worked in the Genetrix program were called back in June 1958 to form the core of a new Air Force squadron, the 6593rd Test Squadron (Special), which would be assigned to retrieve the Corona film buckets and their precious cargo.

One key difference related to retrieving film canisters existed between the Genetrix and Corona programs. While the difference in the weights between the Genetrix film gondolas and the Corona buckets was significant and created problems of their own, they were easily overcome. The key difference was the speed and angle at which the two objects were recovered. The Genetrix gondolas floated along under a balloon at relatively slow speeds and constant altitudes.

Flight crew from 6593rd Test Squadron - Edwards AFB - 1958

In contrast, the Corona bucket fell back to Earth under a parachute. To catch a falling parachute without overflying it or having it get caught in the moving parts of the aircraft was easier said than done. The pilots, crews, and program engineers spent over two years perfecting and practicing the concepts needed to make the safe capture of falling Corona buckets a reality. The pilots and crews spent the entire Genetrix program and first year of the Corona program flying C-119J aircraft; but in 1961, they began to phase the JC-130 four-engine aircraft into their operations as it became available, providing them greater endurance and safety as they flew above the Pacific Ocean.

On 19 August 1960, Capt Harold E. Mitchell and the crew of *Pelican 9* completed the first successful capture of an object from space returning to Earth after they snagged the film bucket from Corona 14 about 300 miles southwest of Hawaii. In the next 12 years, the “Star Catchers” of the 6593rd retrieved 158 film buckets from Corona missions, culminating on 31 May 1972 when Capt Donald G. Hard caught the second recovery bucket from Corona 145, the final Corona mission. After that mission, the 6593rd Test Squadron (Special) was deactivated, and their personnel and equipment were assigned to the 6594th Test Group, which continued the tradition and retrieved the film buckets from 79 successful Gambit missions and 19 successful Hexagon missions through 1984.

LIKE THE FOTOMAT

After 26 years and hundreds of successful recoveries, film return as an aspect of national reconnaissance eventually became obsolete. With the deployment of a near real-time imagery system in 1976, film return satellites had become slow and redundant. The 20th and last Hexagon mission in 1986 was the last film-based satellite launched by the NRO, and film return for national reconnaissance slowly migrated into the history books.

INTEGRATED SYSTEMS

BACKGROUND

When people think of satellites in space, they usually imagine that satellites operate independently and perform a single function. In the earliest days of satellite development, that was typically the case. However, the NRO early in its development of satellites recognized that every satellite vehicle provided a potential means for orbiting more than a single collection function. Given the significant costs of launching a satellite, the NRO built satellites that utilized full lift capacity for each rocket by incorporating, in some cases, additional collection systems. Today those satellites are identified as multi-mission vehicles, an approach to satellite development that the NRO trailblazed. Additionally, the NRO recognized that multiple satellites should act in concert, where possible, and developed the concept of integrated space architecture. Finally, the NRO moved away from single satellite system ground architecture to a more fully integrated ground architecture supporting the integrated orbiting architecture.

SAMOS

The nation's first reconnaissance satellite program, Samos, embraced the notion of a multi-sensor satellite. The primary imagery system carried a 36-inch lens for photoreconnaissance collection, but there were also plans for extra sensors to collect other types of imagery. Additionally, Samos was designed to include signals collection satellites that could collect both analog and digital signals. Samos satellites were envisioned as flying in a single architecture utilizing an integrated ground architecture.

CORONA AFTRACK

When the NRO declassified the Corona program, one capability remained classified for many more years. The first recovery was a test vehicle and did not carry film. Instead it carried a U.S. flag to confirm the return of an object from space. What the NRO kept classified is that Corona mission was an operational mission. It carried a signals collection sensor on the rear of the Agena control vehicle that confirmed the Soviet Union could track U.S. satellites. Additional Corona vehicles would not only capture intelligence imagery, but also carry similar integrated signals collection sensors. Because of the location of the sensor, the program was codenamed AFTRACK.

CORONA AND MAPPING CAPABILITIES

The NRO also recognized that satellite vehicles could be configured for different collection purposes. An early problem that the NRO addressed was the collection of imagery that would enable better mapping in support of military operations. At the time Corona first orbited, the U.S. military was still heavily dependent on German maps captured from World War II for planning defenses against the Soviet Union. Those maps were both imprecise and incomplete. The Air Force envisioned a mapping and charting system named the E-4 Mapping Satellite. Alternatively, the Corona program cooperated on the Argon project that incorporated a mapping camera into the Corona satellite platform to provide imagery for improving mapping capabilities. Again, integrating a new capability into an existing platform further demonstrated the integration philosophy of the NRO.

GAMBIT AND HEXAGON

Like with the Corona program, the NRO did not reveal all aspects of the Gambit and Hexagon programs with their initial declassification. By the time the Gambit and Hexagon vehicles were successfully developed, launch capabilities had significantly improved since the early Corona launches. With improved launch capabilities, the NRO could launch heavier payloads into space, which offered more integration opportunities. Both Gambit and Hexagon vehicles carried passenger payloads—usually signals collections satellites—that typically detached from the primary imagery vehicle. In some cases, however, they remained attached to the primary imagery vehicle, collecting signals in a low earth orbit.

First the Corona, and later the Hexagon vehicles served as companions to Gambit vehicles. Corona and the follow-on Hexagon program collected images of broad areas of interest allowing the U.S. to identify areas and objects of interest. The NRO then carried out Gambit missions to surveil those areas and objects with much higher resolution which provided significant intelligence details. The broad area search capabilities of Corona and Hexagon satellites integrated with the high resolution surveillance capabilities of Gambit provided an efficient and effective means for better understanding the capabilities of the Soviet Union and other adversaries during the Cold War.

Similar to flexibility offered by Corona, Hexagon allowed for much improved mapping imagery. Twelve of the 19 successful Hexagon satellite launches included a mapping camera system. The mapping camera had a separate optical system, film supply, and recovery vehicle. It was attached to the Hexagon vehicle and allowed collection of broad area search imagery and mapping imagery at the same time, again demonstrating the NRO's space system integration philosophy.

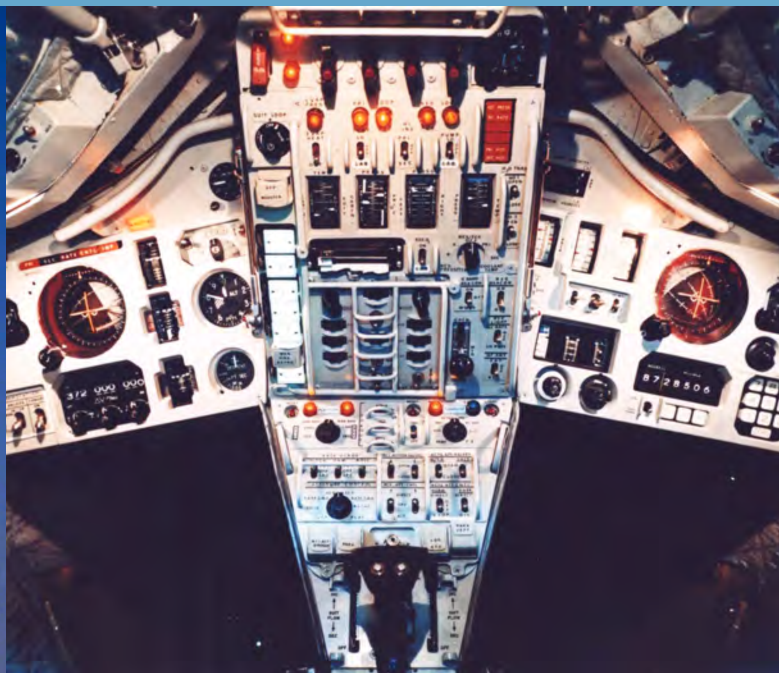
KENNEN

In 1976, the NRO launched its first electro-optical satellite known as Kennen. The Kennen satellite depended on a relay satellite in order to transmit imagery in near real-time. The use of a relay satellite further advanced NRO efforts to integrate satellites into a unified architecture.

A MATURE INTEGRATION PHILOSOPHY

The integration philosophy continues today with the NRO efforts to incorporate multiple sensors into an integrated architecture of satellites. This longstanding integration approach developed by the NRO consistently improved the efficiency of NRO satellite development and the effectiveness of satellites in low-earth, geosynchronous, and highly elliptical orbits. As the NRO improved satellite integration efforts, it has also improved the integration of ground stations. On both fronts, the NRO's integrated architecture provides robust and resilient intelligence collection capabilities necessary to maintain the U.S.'s national security in a very uncertain world.

MOL



A PRESIDENTIAL DECISION

President Lyndon Baines Johnson was not afraid to embrace government programs that might bring about significant change if successful. On 25 August 1965, he announced the following to the American Public:

> *At the suggestion of Vice President Humphrey and members of the Space Council, as well as Defense Secretary McNamara, I am today instructing the Department of Defense to immediately proceed with the development of a Manned Orbiting Laboratory. This program will bring us new knowledge about what man is able to do in space. It will enable us to relate that ability to the defense of America. It will develop technology and equipment which will help advance manned and unmanned space flights. And it will make it possible to perform their new and rewarding experiments with that technology and equipment.*

The Manned Orbiting Laboratory, or MOL as it was known, promised to use space for the first time as a manned reconnaissance vantage point. If successful, the program could dramatically change the way the United States collected intelligence on its adversaries, including the nation's main foe, the Soviet Union.

THE DORIAN PROGRAM

In the early 1960s the Air Force began efforts to put Air Force members into space by developing the Manned Orbiting Laboratory. The Air Force described the MOL program as follows in its initial December 1963 press release announcing the project:

> *The MOL program, which will consist of an orbiting pressurized cylinder approximately the size of a small house trailer, will increase the Defense Department effort to determine military usefulness of man in space...MOL will be designed so that astronauts can move about freely in it without a space suit and conduct observations and experiments in the laboratory over a period of up to a month.*

The U.S. Air Force described the MOL program as a less expensive option that would allow the Air Force to "conduct military experiments involving manned use of equipment and instrumentation in orbit and, if desired by NASA, for scientific and civilian purposes." From the beginning of the program, however, U.S. officials questioned the need for the MOL in addition to the U.S.'s civilian space program.

Unbeknownst to the public, the MOL program included a highly secret set of experiments and capabilities to gain intelligence from space. Information about MOL's secret planned capabilities was strictly protected under a security compartment known as Dorian. The capabilities developed under the Dorian project would result in the United States using the MOL as a manned reconnaissance station in space, collecting both imagery and signals intelligence. If achieved, the MOL would allow the U.S. to overcome the limitations of the already successful Corona and Gambit satellite reconnaissance programs.

The Dorian camera system was developed by Eastman Kodak, the same company that developed the high-resolution camera system used on the Gambit photoreconnaissance satellite. The Dorian camera system would have some unique capabilities. First, it had a longer focal length and other improvements, permitting better resolution than the first generation of Gambit satellites. Second, the camera system would be used after MOL crew members used a spotting scope system to determine whether or not targets were clear for imagery. Third, imagery targeting priorities could more readily be changed to meet unexpected imagery opportunities. And fourth, the MOL crew members would be trained to repair the Dorian system in the event that there were malfunctions preventing successful imaging. Together, these capabilities mitigated the shortcomings of the Corona and Gambit photoreconnaissance satellites.

MOL CHALLENGES

The resources devoted to the Vietnam War, the War on Poverty, and the Apollo program competed with the resources needed for the MOL project. Additionally, the NRO had already demonstrated that space could be used successfully as a reconnaissance platform through the Corona, Gambit, Grab, and Poppy satellite programs. At the time MOL was proposed, the NRO already had plans for a more powerful high-resolution Gambit program and the CIA was in the early stages of developing a satellite to supersede the Corona program, and they hoped, the Gambit program too. That program evolved into the NRO's Hexagon program. The Hexagon program was designed to carry an immense film load, allowing it to stay on orbit for six months or more. It would also carry an improved targeting system. It promised versatility that called into question MOL's necessity. Eventually, Hexagon and the improved Gambit-3 system would suffice in the Nixon administration's view, leading to the MOL's termination in June 1969.

MOL Crew Members

THE MOL PROGRAM LEGACY

Because of the MOL program size, complexity, and time in existence, it consumed many millions of dollars in funding before termination. This begs the question of what if anything did the United States gain from the program? There were significant legacy contributions from the program. The first and foremost significant contribution was the leadership that came from the MOL crew members trained under the program. Seven of those crew members were accepted into NASA's astronaut program. At NASA they would either command or pilot the Space Shuttle. Of those, one would eventually lead NASA as the agency's Administrator, another would command NASA's Cape Canaveral launch facility, and others would lead elements of the NASA space program. Yet another would go on to lead the U.S.'s Strategic Defense Initiative. Another would serve as Vice Chairman of the Joint Chiefs of Staff. Many would also play important roles in corporations supporting national defense and space programs. Other engineers, scientists, and staff would play key roles in other national reconnaissance programs, drawing on their experiences and insights gained from the MOL program.

The MOL program would also make important contributions to national reconnaissance and space exploration programs. The Dorian camera system was to be preserved and studied for possible incorporation into the Hexagon program. One of the options for reducing costs of the MOL program was a series of unmanned missions. Those missions would carry multiple film return capsules in a configuration that closely resembled the configuration eventually developed for the Hexagon program. The MOL program also included a segmented mirror technology that was eventually used in a domestic space observatory. Segmented mirrors offered additional advances in space exploration with MOL advancing this important technology.

Finally, MOL helped advance the technology and science necessary for longer space missions. For example, the MOL program required its crew members to travel through a narrow tube or tunnel from the Gemini capsule to the laboratory section once the vehicle was on orbit. This in turn required a flexible space suit—more so than what NASA had developed at the time. The advancements in space suits under the MOL program were transferred to NASA. MOL also included proposals for more than one space module being launched and then linked on orbit. This concept would be critical for the development of today's multi-module space craft on orbit such as the International Space Station. The research and technology developed under the MOL program for sustaining crew members on orbit was also transferred to NASA, undoubtedly aiding NASA's advancements in manned space flight.

MULTIPLE ORBITS

The NRO has acknowledged that it flies satellites in three types of orbits: Low Earth Orbit (LEO), Highly Elliptical Orbit (HEO), and Geosynchronous Orbit (GEO).

LOW EARTH ORBIT (LEO)

The NRO's first satellites, the GRAB Elint satellites and the film-return photoreconnaissance satellites of the Corona program, flew in LEO. Subsequent programs including Poppy, Gambit, and Hexagon, likewise flew in this orbit. Satellites in LEO fly relatively close to the Earth's surface, up to 2,000 km in altitude. In LEO, orbital periods are short – often completing a pass over the Earth in just 90 minutes. In general, LEO satellites can make up to 16 complete passes in a day, but they must, by definition, make at least 11.25 passes. Satellites in LEO fly at high velocity, averaging around 7.8 km/second. Due to their close proximity to Earth, LEO satellites offer a limited field of view and are only able to communicate with small portions of the Earth at a time. Therefore, most satellites in LEO require a network or constellation in order to provide continuous coverage. In low altitude, satellite life expectancy remains low due to atmospheric drag (an important factor that has historically precluded flying satellites below 300 km), and they require periodic reboosting in order to maintain a stable orbit.

Within the LEO orbit, there are several subsets based on inclination and altitude. The Equatorial Low Earth Orbit (ELEO) indicates an orbit with a low inclination to the equator, offering rapid revisit times. Conversely, with a high inclination rate, Polar Orbits offer satellite passes above or nearly above both poles. In recent years, more objects have begun flying in Very-low Low Earth Orbit (VLEO). These objects require new and developing technologies to combat the significant atmospheric drag and maintain orbit, and yet remain economically sustainable.

Despite any limitations of the LEO orbit, it lends itself to manned missions and more accessible servicing. It is the most common orbit for reconnaissance satellites and all other man-made objects. The International Space Station flies around 330 km above the Earth's surface; the Chinese Tiangong Space Station, launched in April 2021, orbits between 340 and 450 km; and the Hubble Space telescope orbits at about 540 km. Unlike most communication satellites, a series of satellites operated by Iridium Communications operates in LEO at about 780 km. And finally, remote sensing satellites often fly around 800 km and near polar inclination.

The United States Strategic Command (USSTRATCOM) currently tracks more than 8,500 objects that are larger than 10 cm in LEO. Because it is the preferred, oldest, and most accessible orbit, LEO is becoming crowded, putting objects at risk of catastrophic collisions.

HIGHLY ELLIPTICAL ORBIT (HEO)

Objects that experience a much higher high point (or apogee) than its low point (or perigee) are flying in a Highly Elliptical Orbit. The most common type of HEO is the Molniya orbit, "lightning" in Russian. From their latitude, the Russians found that it required too much energy to launch communications satellites into Geosynchronous Orbit, as many other nations were doing in the 1960s. So in 1965, Russia began launching into HEO, making them the original user of the orbit. Russia continued to launch their series of Molniya satellites, both military and communications, until 2004. Objects in a Molniya orbit make two full passes over Earth in a day, flying in a highly inclined orbit, and are generally marked by an Argument of Perigee at the Southern Hemisphere. Given the nature of the orbit, satellites slow as they approach and descend from apogee, offering long-dwell collection opportunities. Objects in Molniya orbit are near apogee for about 11 of their 12-hour orbit time, ideal for coverage around the North Pole and for space-based ballistic missile early warning systems. Marked by high apogees, satellites in HEO are under far more severe solar and lunar gravitational terms than satellites in LEO, requiring high-precision modeling in the orbital mechanics of a HEO satellite.

A much lesser-known type of HEO, the Tundra orbit, similar in characteristics to Molniya, offers only one pass over Earth per day. With only one pass, satellites in Tundra are near apogee for about 16 hours of their 24-hour orbit. The only known user of the Tundra orbit is Sirius Satellite Radio, which operated satellites in Tundra from 2000 to 2017. Communication satellites fly predominantly in HEO.

GEOSYNCHRONOUS ORBIT (GEO)

Unlike satellites in LEO, satellites in GEO fly at high altitude – around 35,790 km above the Earth's surface. At such a distance, satellites in GEO follow the Earth's rotation and sidereal day, marked by an orbital period of just 3 minutes and 56 seconds shy of 24 hours. The orbit was first described by Herman Potcnik in 1929, although it wasn't until 1945 when the British science fiction author, Arthur C. Clarke, first popularized the idea of the orbit in his paper, "Extra-Terrestrial Relays- Can Rocket Stations Give Worldwide Radio Coverage?" GEO is sometimes referred to as the Clarke Orbit. Designed by Harold Rosen at Hughes Aircraft, in 1964, Syncom 3 became the first satellite successfully placed in GEO. It transmitted the summer Olympics from Japan to the United States

A geostationary orbit, a type of geosynchronous orbit marked by zero degrees of inclination and zero eccentricity, remains over the same spot on the Earth's equator at all times. From such a high altitude, satellites in geostationary orbit can offer a large, constant view of the same spot on Earth – making this orbit a favorite for weather and communications satellites.

An inclined geosynchronous orbit (IGSO) is geosynchronous but not geostationary. At an incline other than zero degrees, the ground track of a satellite in IGSO can vary from a straight line of longitude around the equator to a non-symmetric analemma (or figure-8).

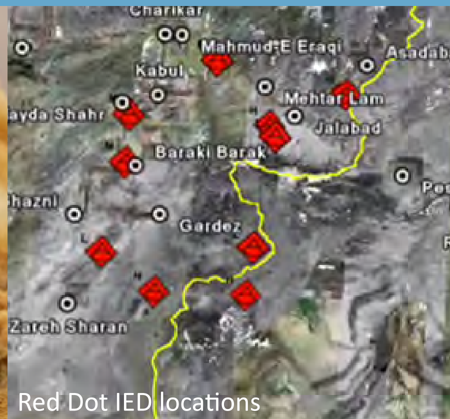
Satellites that fly in GEO include INMARSAT, a fleet of 11 telecommunications satellites operated by the International Mobile Satellite Organization, an international telecommunications company founded in 1979. The Thuraya Satellite Telecommunications Company, a regional mobile satellite system that covers 110 countries across the Indian subcontinent, the Middle East, Central Asia, North and Central Africa, and Europe, likewise operates two satellites in GEO. Intelsat also flies in GEO.

Because all satellites in GEO must occupy the same ring above the equator, there are a limited number of slots available for satellites. The International Communications Union addresses and navigates disputes over accessibility to the available GEO slots.

NRO IS EVERYWHERE

The three types or orbits are all distinctly different from each other. Each offers particular advantages, as well as disadvantages. The type of satellite usually determines the orbit, since the satellite's mission will be benefited by a certain orbit, while the orbit's detriments can be lessened or nullified based on the mission and target(s). The NRO has declared that it uses all three orbit types in its constellation.

RED DOT



Red Dot IED locations

The NRO has played a key role in operations against al-Qa'ida and other terrorist organizations, as well as U.S.-led military operations against insurgencies in Iraq and Afghanistan. These adversaries often operate as dispersed, clandestine networks, hiding in isolated, rugged locales like the Afghan-Pakistan border, or in hostile ungoverned regions of Somalia or Yemen. These adversaries are successful in their use of technology, and a favored weapon is the improvised explosive device (IED).

THE HIDDEN THREAT

Cheap and easy to construct, IEDs allow lightly armed and barely trained militants to engage with deadly consequences against the well-equipped and highly-trained troops of U.S. and coalition forces. IEDs tip the balance in an asymmetric conflict by enabling insurgents to inflict mass casualties without exposing themselves. The unpredictable, combat-avoiding nature of IED attacks are what makes them so effective. In the past, IEDs slowed the mobility of U.S. troops while time-consuming sweeps for concealed devices were conducted. In the early days of the Global War on Terror, the only defense against IED attacks was equipment such as radios, metal detectors, electronic counter-measure systems, and robots.

IEDs are one of the most lethal weapons available to terrorists and enemy combatants, as they are not only simple to build and deploy, but also virtually undetectable, and they frequently produce high casualty counts. The Defense Manpower Data Center reported that from 7 October 2001 through 16 September 2006, IEDs caused about half of all the American casualties in Iraq, and about 30% of combat casualties in Afghanistan. Separately, a U.S. Government Accountability Office report stated that between January 2007 and February 2018, approximately 9,000 IED incidents were targeted against U.S. and allied military forces in Iraq and Afghanistan, resulting in about 23,000 casualties.

THE NRO DEPLOYS RED DOT

One of the most successful efforts to date in countering the IED threat faced by U.S. and Coalition Forces is the RED DOT program. Developed by the NRO and initially deployed to Iraq in early 2010, and later to Afghanistan, the program leverages information from multiple intelligence sources to provide an integrated IED risk situational picture that is delivered directly to the warfighter in harm's way. It works by monitoring roadways for the electronic signals produced by the transmitters used to trigger the explosives, and within minutes, combines those signals with other intelligence streams, terrestrial sensors, and imagery to narrow the IED location to an accuracy within a few meters. It then sends the information directly to the tactical user on the ground, indicating where the possible IEDs may wait ahead, thus enabling the troops to avoid the area and ultimately remove the IED from the battlefield.

It takes an incredible amount of skillful integration of signals and imaging satellite intelligence with other source inputs in order to display, quite literally and within minutes of receipt, a red dot on the computer display in the vehicle on the ground. That dot identifies, in near real-time, the probable location of deadly IEDs. Former DNRO Bruce Carlson said, "It's incredibly difficult to take a picture someplace and fuse it with signals intelligence that you might have a million different pieces of." However, the one thing that is certain is that RED DOT saves lives by providing the integrated information needed to avoid and successfully remove hundreds of IEDs from the battlefield every year.

RELAY SATELLITE DEVELOPMENT

Electric Telegraph Receiver

Traveling Wave Tube Amplifier

GAME-CHANGING INTELLIGENCE COLLECTION INNOVATION

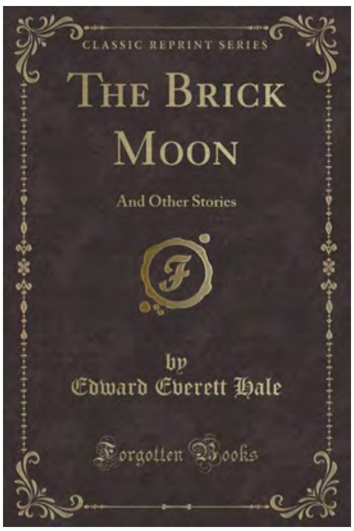
The NRO's implementation of communications relay satellites enabled near real-time return of high-resolution, digital reconnaissance imagery, among the most important intelligence collection innovations in the organization's history. The first relays served as integral components of the Kennen electro-optical imaging satellite system. Beginning in January 1977 when Kennen became operational, the relay satellites formed the space segment downlinking collected digital data to a receiving mission ground station, which converted it into hard copy imagery. This game-changing capability provided the U.S. an immediate technological edge and intelligence advantage in conducting diplomatic and military actions. For the first time in history, decisionmakers in Washington could obtain digital imagery within hours of collection or tasking, allowing the monitoring of an emerging or ongoing crisis happening nearly anywhere in the world. The Kennen system also ushered in a new era of tactical responsiveness for military commanders, who could use the high-quality, time-sensitive imagery for planning, targeting, and executing missions. Development of relay satellites, which NRO needed four years to complete, made instantaneous downlinking possible by solving the line-of-sight and weather problems that since ancient times had limited long distance communications methods, ranging from smoke or light signals to semaphore and even radio telegraphy.

QUEST FOR LONG DISTANCE COMMUNICATIONS LINKS

The first long-distance communication method that overcame these problems and promised to provide timely messaging was the electric telegraph. Long distance communication links were established by the laying of network cables along the bottom of oceans, which provided telegraphic messaging capability, first between England and Europe in 1850, and later between Europe and North America in 1866.* By the early 20th century, the telephone and wireless communications began to supplant the telegraph; early wireless systems, in particular, transmitted in frequency ranges below 30 MHz that reflected signals off the ionosphere and the Earth's surface to follow the curvature of the planet, providing unlimited range. All these innovations greatly improved and accelerated long-distance communications, but as radio frequencies above 100 MHz began to be used, the old problem resurfaced: higher frequency waves were not reflected back, but simply traveled into space, meaning that transmissions could only be received when the transmitter and receiver were in line of sight of each other. The solution for integrating higher frequencies into global communications would require a space-based system, but few had thought seriously about this problem yet. One early fantastical concept, as online

*In 1858, the Atlantic Telegraph Company, a joint Anglo-American venture, had successfully laid cable along the ocean floor stretching from Valentia, Ireland to Heart's Content, Newfoundland. Unfortunately, the cable was already in deteriorated condition before installation, and further damage caused by sending higher than necessary voltage through the line caused the communications link to fail after only three weeks. It would take eight years, during which time engineers continued to refine cable construction, until the Atlantic Telegraph Company laid a reliable cable, and transatlantic telegraph service could truly begin.

Encyclopedia Britannica notes, appears in American author Edward Everett Hale's 1870 short story, "The Brick Moon," which features signal communications between people on the Earth and others residing on a primitive space station. In the story, a group of men decides that having a second moon would be enormously beneficial to navigation, so they build a structure 200 feet in diameter, made of bricks, and launch it into space. Once in orbit, the "Brick Moon" satellite transmits Morse code signals to navigators by having people jumping up and down on the satellite's surface. Imaginative, perhaps, but clearly lacking understanding of what a later writer would call "the peculiarities of the ionosphere."



EXTRATERRESTRIAL RELAYS

That writer was Arthur C. Clarke, who was destined to become an enormously popular science fiction author and essayist. In 1945, Clarke—who was then an unknown Royal Air Force Officer—began ruminating on the limitations of long-distance communication and the possibilities for using satellites to provide a true broadcast service over the whole globe. In a Wireless World article published that October, Clarke postulated that artificial satellites in 24-hour orbits (i.e., moving at the same speed as the Earth's rotation, thus remaining in a fixed position relative to a point on Earth, eventually called geostationary orbit) could intercept radio signals, amplify them, and retransmit to other relay satellites or ground receivers. By placing three such satellites 120 degrees apart, Clarke calculated his extraterrestrial relays constellation could provide television and microwave coverage to the entire planet. Although it did not garner much immediate attention, Clarke's concept was essentially correct and pointed toward a future of space-based communications. Moreover, although not stated, relay satellites would prove critical to addressing the bedeviling line-of-sight delays that would occur with still-nascent orbiting sensor payloads, which could not downlink data to the Earth without being in clear view of a ground station. The result is significant time lag between when sensor data is collected and when it is finally received by the processing station. A constellation of two or more relay satellites compensate for this by working in tandem to continuously transfer data and command instructions to and from the ground. The operations of relay satellites have been compared to their namesake racers in track and field: like runners carrying and passing off batons on a relay team, the individual satellites hand off data to the next satellite to carry it on the next leg of its journey.

Fortunately, technology was not dependent upon Clarke's readership. The same year his article appeared, the U.S. Army Signal Corps reflected radar pulses off the Moon back to a terrestrial antenna. John R. Pierce of AT&T's Bell Laboratories expanded upon Clarke's ideas by suggesting the use of a space communications "mirror" in conjunction with a medium orbit "repeater" and a 24-hour orbit "repeater." By the end of the 1950s, Navy stations on both U.S. coasts and at Pacific sites transmitted messages, including facsimiles, using "lunar bounce." Working for NASA, Pierce's Bell Labs team developed the first active relay Telstar 1, which transmitted live television images between North America and Europe in 1962. Another influential engineer, Harold Rosen, led a Hughes Aircraft Company team in launching the first satellite into a geosynchronous orbit, Syncom 2, as well as the first geostationary orbit satellite, Syncom 3. Similar technological developments paved the way for NRO's implementation of its relay satellite system.

PIONEERING CONCEPT AHEAD OF TECHNOLOGICAL READINESS

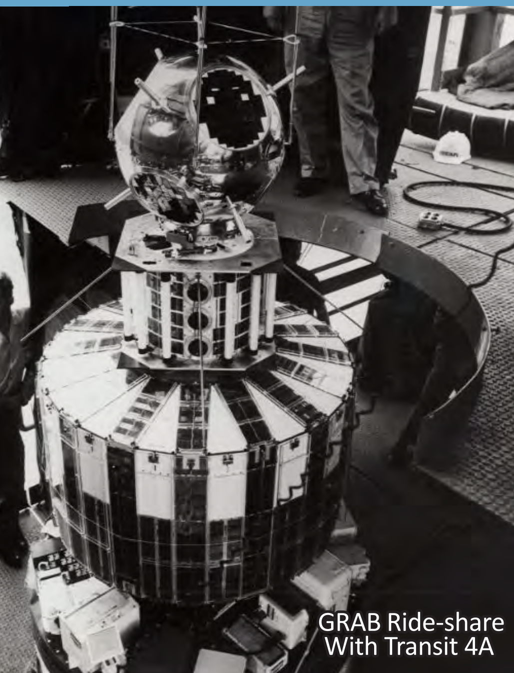
Developing systems capable of providing timely data to warn of an imminent attack had been a principal national reconnaissance objective in the first U.S. satellite program, the Air Force's WS-117L begun in the late 1950s and contracted to Lockheed. Also encompassing plans for a family of systems to collect electronic and infrared intelligence, the WS-117L program's primary photoreconnaissance satellites consisted of systems employing both film-readout, which provided more timely data return, and film-return technologies, which promised greater image resolution and ground coverage potential. The former were developed under the Sentry (later renamed Samos) program, and though electronically scanning film negatives and transmitting the data to the ground was indeed more timely, the technological state-of-the-art limited scanning capacity and degraded image resolution. This left the latter, separated from WS-117L and developed covertly under the Corona program, to become the first operational photoreconnaissance system. The tremendous success of Corona—the NRO launched and operated Corona satellites for 12 years, continually improving cameras and extending mission duration—particularly its innovative film-recovery method, ensured that it became the blueprint for two successor film-return systems, Gambit and Hexagon, that further advanced space reconnaissance technology. Still, the need for a near real-time capability persisted as, too often, returned imagery that was found to contain time-sensitive information became available only after effective follow-up action could be taken. One frequently cited example occurred in August 1968, when Corona imagery revealing an impending Soviet invasion of Czechoslovakia was returned from space, processed, exploited, analyzed, and delivered to President Johnson's office more than a week after Warsaw Pact troops had largely suppressed the "Prague Spring." Confronted with a fait accompli—not to mention evolving policies crafted to lessen East-West tensions and NATO allies opposed to military intervention in the Soviet sphere of influence—all the President could do was cancel a scheduled U.S. - U.S.S.R. summit and issue a toothless diplomatic protest.

By the late 1960s, NRO Program B was already studying major technologies and subsystems needed for an EOI satellite system that would meet the requirements for a near real-time indications and warning capability. The envisioned system's primary method for image recovery was expected to be relay satellites, and though some additional technology development would be required, the NRO contemplated building relays that closely resembled communications satellites then under development. In particular, Intelsat-3, an American communications satellite developed by TRW and used to relay commercial global telecommunications, including live TV, was considered a close approximation to what NRO would require for its relays, albeit with less demanding specifications. Thus, study teams at that time did not consider this essential component to the EOI system to pose daunting engineering challenges. This assumption proved to be overly optimistic. As events unfolded following President Nixon's approval on 23 September 1971 to proceed with development and acquisition of the revolutionary EOI system, the NRO discovered there are always unexpected challenges when an organization redefines state-of-the-art.

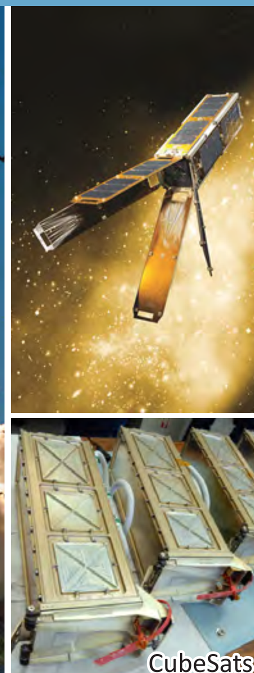
MAXIMIZING PROGRAM MANAGEMENT EFFECTIVENESS TO ACHIEVE THE CRITICAL LINK

After the relay satellite contract award to Hughes Corporation one year later, the NRO scientists and engineers set about designing and building first-of-its-kind hardware. To meet challenges, NRO engineers adopted and adapted existing commercial components where possible. Enabling the relay satellites to operate in conjunction imagery satellites was another challenge absent in the use of commercial communication satellites system. Finally, the choice of orbit was critical, and NRO sought inspiration from Clarke's hypothesis from some 30 years earlier. For the other issues, the NRO team worked round-the-clock to overcome many challenges in getting the spacecraft ready for launch, to include compiling test procedures from scratch. In the months leading up to the first launch, the prime contractor took the unprecedented step of assigning its chief engineer—later named a Pioneer of National Reconnaissance—to work full-time to ensure complete mission success. In the end, the NRO launched the relay satellites on-time and without significant cost overrun. The new architecture eliminated the country's dependence on film-return systems and provided a persistent global information perspective that supported decision-making on emerging crises.

RIDE-SHARE LAUNCH


GRAB Ride-share With Transit 4A


Space Shuttle


CubeSats


NROL-36

NRO has innovated by exploring and exploiting ways to launch its satellites. Rideshare launches are a key example of its innovative approaches. In essence, ride-sharing connects passengers with available transportation. A secondary payload, or "ride-share," is a smaller-sized payload that is transported to orbit on a launch vehicle supplied by or for the entity associated with the primary payload. Typically, the primary payload dictates the specific requirements for launch and the launch-vehicle interface. In return, the ride-share gets into orbit at a substantially reduced price.

EARLY NRO RIDE-SHARING

Ride-sharing is not a new concept for the NRO. The idea of launching more than one payload together dates back to NRO's very beginnings. The first electronic intelligence satellites were small, and launch procedures were rather fluid. Two or three satellites might be stacked and then joined together in what was called a "piggyback" launch, sending the main satellite and one or more auxiliaries together into orbit. After reaching orbit, the payloads typically would separate to perform their individual missions.

Galactic Radiation and Background 1 was the first operational U.S. intelligence satellite. It accompanied the first U.S. Navy navigation satellite, which was called Transit 1B, as a covert piggyback payload. Then, as in more recent times, the organization with the main payload determined the launch schedule. On 22 June 1960, the two satellites launched together from Cape Canaveral, Florida, using a Thor-Able-Star booster. Although details including GRAB 1's name and Elint mission remained classified, the news media celebrated this first U.S. dual launch as an important space accomplishment. GRAB 2, the next successful Elint satellite, launched on 29 June 1961. It was piggybacked with the Transit 4A satellite and a satellite designed by Dr. James Van Allen of the University of Iowa to study the radiation belts around the Earth. That was the first successful launch of three satellites together.

As the NRO began to develop larger and more complex satellites that in turn required powerful boosters, the opportunity arose for it to host secondary payloads systematically. The NRO's Program A operated an experimental program to collect Soviet radar information in which smaller payloads were attached to a rack on the rear or "aft" section of the Agena satellite vehicle for launch. This configuration received the very logical program name "AFTRACK." The first AFTRACK experiment, SOCTOP, successfully launched along with a Corona satellite on 10 August 1960. Subsequent AFTRACK experiments had imaginative names that included TAKI, GRAPE JUICE, NEW HAMPSHIRE, PLYMOUTH ROCK, WILD BILL, and OPPORKNOCKITY. The last AFTRACK ride-share, DONKEY, launched on 24 July 1967.

Sigint "Proof of Concept" subsatellites flew as aft-rack "hitchhikers" on Corona, Poppy, and other launches. Other secondary payloads were the Sigint Project platforms. These Program 11 (P-11) subsatellites detached from the primary satellite and proceeded with their missions. Designed to be longer lived than the AFTRACK experiments, these were bona fide subsatellites with their own propulsion systems.

NRO AND THE SPACE SHUTTLE

For a period of time, all NRO and DoD payloads were directed to launch solely via the Space Transportation System, more commonly known as the Space Shuttle. In fact, plans to use the shuttle to launch the very large Hexagon system dictated the dimensions of the Space Shuttle's cargo bay. The relationship between the NRO and NASA was complicated. Disasters in the 1980s, including the loss of the *Challenger* and an explosion that damaged a planned shuttle launch site, were serious setbacks. In the end, the actual number of NRO payloads that launched via shuttle missions was limited. The NRO instead chose to develop unmanned launch systems that were more reliable, flexible, and less costly.

RIDE-SHARING TODAY

The term "ride-sharing" became extremely popular in the early 21st century. In the launch arena, the NRO led the way with its CubeSat program. It was a creative approach to launch and operate nanosatellites on orbit at a lower cost, and in a quicker time frame, than traditional NRO programs. This allowed the NRO and a variety of mission partners that included NASA to launch experimental CubeSat satellites that explored new questions and enabled rapid innovation. Small, containerized, modular, and boasting standard interfaces, CubeSats are designed to reach space by hitchhiking as secondary payloads. Ride-sharing got small, low-cost satellites on orbit very quickly.

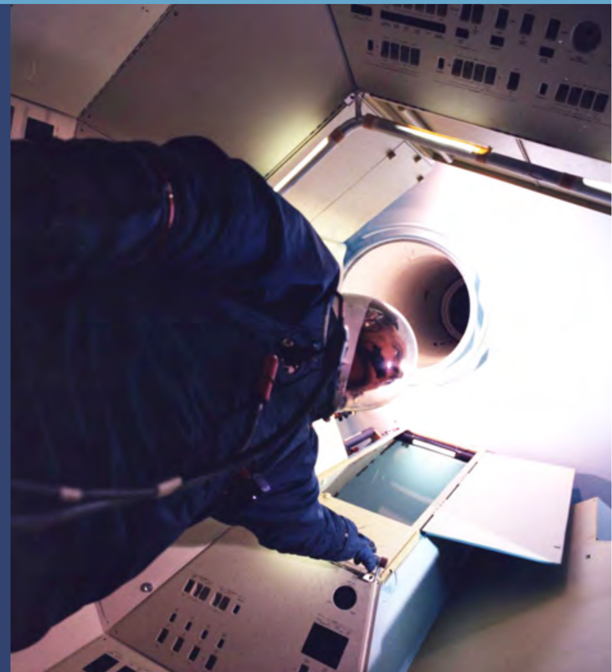
On 13 September 2012, the NRO launched its first ride share mission, NROL-36. The Atlas V rocket boosted the main payload along with 11 CubeSats in the extra capacity bulkhead. These small modular CubeSats had been developed by labs and other organizations to research such topics as maritime shipping container tracking and space weather.

The costs of developing a CubeSat, and of securing a launch slot for it on a larger mission, are substantially lower than single-purpose launches. Reaching orbit as a ride-share allows CubeSat missions to take on more risk with the potential for substantial rewards on investment. Another key factor fueling the success of ride-sharing at the NRO was the development of inexpensive deployment systems to propel the ride-shares into space after the primary payload deployed.

The NRO CubeSat Program Office accepted cutting edge ride-share payloads from government, academia, and industry. NRO Director Betty Sapp praised ride-sharing in 2013, saying that "[w]e have long recognized that there are benefits and efficiencies to be gained through the ride-share in space launch. These benefits include opportunities to conduct scientific research and demonstrate and apply emerging technologies through the use of small satellites."

Originally a process just for government-sponsored launches, ride-sharing quickly is becoming ubiquitous. The advent of nanosatellites and the expansion of commercial launch providers helped fuel the growth of ride-share launches. Thanks in no small part to the NRO's ride-share innovations, sending a small payload into space may eventually become as easy as shipping a package with a delivery company.

SPACE-BASED LAB



MANNED ORBITING LABORATORY HISTORY

Originally conceived in 1962 and publicly announced in 1965, the Manned Orbiting Laboratory program was a joint NRO-Air Force project designed as a 30-day mission to send reconnaissance-trained military men into space. Once in orbit, the astronauts were to transfer from their Gemini capsule into the laboratory vehicle via a hatch cut into the Gemini's heat shield. There, the astronauts would spend the next 30 days in a shirt-sleeve environment, performing experiments and taking reconnaissance photos of Earth - avoiding disruptive weather conditions and responding to changing national security concerns.

Upon completion of the MOL mission, the crew was to climb back through the hatch and into the Gemini capsule, detach from the laboratory, and return to Earth in the Gemini. The remaining MOL hardware - the entire laboratory vehicle - would become space refuse. Unfortunately, the system was not designed to allow for a rendezvous with a later crew.

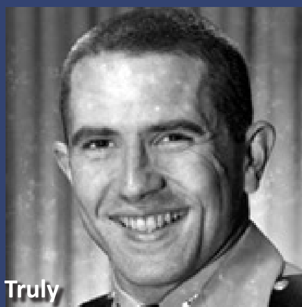
Although the program was cancelled in 1969 before it ever flew, it prompted the design and building of several important pieces of technology that went on to benefit the space community for years to come. In response to the program's cancellation, an ad hoc group chaired by MOL technical director Michael Yarymovych and tasked with finding national benefit from the program remarked, "In this regard, an unmeasurable but real benefit of the program is the expansion of manned spaceflight know-how across a broad segment of industry and Government."

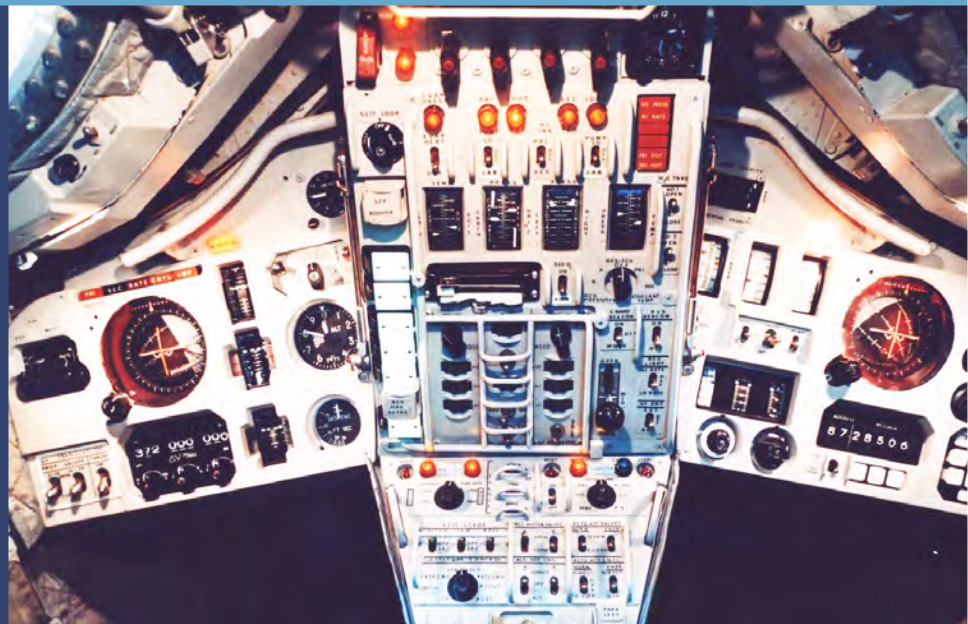
MOL VEHICLE DESCRIPTION

The MOL's Space-Based Lab was composed of a Laboratory Module mated with a Mission Payload System Segment (MPSS). The Laboratory Module was 10 feet in diameter and 19 feet long - the most spacious design for any American spacecraft at the time. It was to be the crew's mission support during the 30-day orbital flight phase. At 1,000-cubic feet, the pressurized compartment was designed to allow for a shirt-sleeve environment for the two-man crew, working and living without constantly wearing their space suits. It was also to provide a living area for the longest anticipated spaceflight to date.

The Laboratory Module was divided into two octagonal workspaces, housing eight bays each. The bays were designed to provide room for storage units, environmental control system equipment, the environmental control system controls, hygiene/waste compartment, a biochemical test console and work station, large experiment airlocks, a glove box for handling liquids, a motion chair to determine mass of crew members during flight, two performance test


Macleay


Truly



panels, a physiology test console, a full-body exercise device, emergency oxygen masks, viewport and instrument panel, and the main spacecraft control station. The module would also be home to beds, spacesuits, food, and water stores to support the astronauts for 30 days.

Within the Laboratory Module, the two-man crew was to conduct their primary function of attaining high resolution, useful reconnaissance photos. Over the life of the program, two MOL astronauts, Lachlan Macleay and Richard Truly, worked to design a targeting software package to make use of man in the program. Using two targeting telescopes, the MOL astronauts would be able to look ahead to planned targets, assess the weather and viability of the target, and vote on which targets to prioritize. The targeting telescopes and photographic equipment were located in the MPSS, while the workstations were housed in the Laboratory Module.

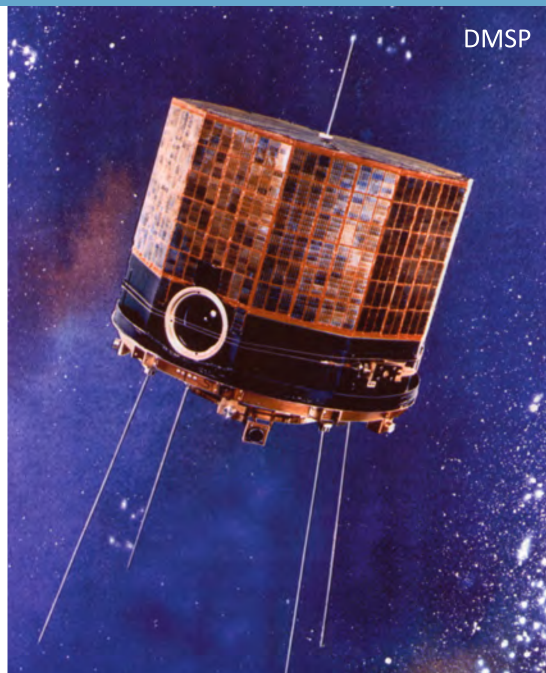
The MPSS was designed to house the photographic system and subsystems necessary for control and dynamics. It was an unpressurized module 10 feet in diameter and 37 feet long. It housed the acquisition and tracking scopes, communication equipment, film processing, and all other equipment required to maintain system functions. Mated with the Laboratory Module, it created the complete Laboratory Vehicle.

MOL LEGACY

When the program was cancelled in June 1969, officials made the decision to transfer all crew-related equipment, as well as the Gemini, to NASA. It was a prolonged transfer process, but NASA was in possession of all manned system components, including the Laboratory Module Simulator and the Mission Simulator, by the end of 1973. The MOL's waste management system eventually flew on Skylab, and several other pieces of MOL equipment contributed to the NASA Earth Science research program. Additionally, MOL's acquisition and tracking system, which became the centerpiece of the program, as well as the mission development simulator, contributed to the success of NASA's earth sensing program. Although the program's cancellation was a disappointment to many involved, pieces of MOL undoubtedly contributed to a variety of space-related missions across government and industry in the decades that followed.

WEATHER SATELLITES


TIROS Launch


DMSP


DMSP Satellite image of U.S. at night

BACKGROUND

In the mid-1950s, the RAND Corporation warned U.S. Air Force officials that accurate and timely meteorological forecasts depended on cloud-free photography, prompting the establishment of the DMSP program to support the joint CIA and Air Force program. The Corona satellite was first launched in 1960. Corona satellites took photographs from space enabling the U.S. to both monitor meteorological forecasts and track threat activity in denied areas like the Soviet Union. Though Corona's photoreconnaissance capability was remarkable for the time, in the early days its imagery was difficult to interpret and expensive to process in a timely way. The Corona program operated from 1960-1972 and was the U.S.'s first photoreconnaissance satellite and foundational to the development of satellites designed for meteorological purposes.

TELEVISION INFRARED OBSERVATIONAL SATELLITE (TIROS-1)

On 1 April 1960, a satellite designed by the Radio Corporation of America (RCA) and launched by NASA became America's first weather satellite. While TIROS-1 only operated for 78 days, the program demonstrated that cloud cover and weather patterns could accurately be monitored from space—in contrast to blurry images obtained from Corona's early missions in 1960-1961. In April 1961, after an interdepartmental study on weather satellites concluded, NASA was chartered to establish requirements for the development of meteorological satellites for the Department of Commerce and DoD under the umbrella of the National Operational Meteorological Satellite Program (NOMSS). This program, many believed, would avoid duplication of effort and produce at less cost a single satellite system to meet civil and military weather forecasting needs, including National Reconnaissance Program's requirements. TIROS 1 then became the model for subsequent civilian and military meteorological satellites.

DEFENSE METEOROLOGICAL SATELLITE PROGRAM (DMSP)

In July of 1961, at the height of the Cold War, Joseph Charyk, Under Secretary of the Air Force and NRO Director, became concerned that NOMSS was designed mainly for civil programs, which did not always align with NRO's classified mission requirements. For that reason, Charyk authorized the development of four "Earth-referenced" wheel-mode weather satellites to be launched using NASA's Scout boosters as an "interim" solution for NRO. In tandem, DMSP under NRO established the technology and flight operations for polar orbiting, low-altitude national weather satellite systems administered by the National Oceanic and Atmospheric Administration (NOAA). In the following months, NRO-DMSP funded weather satellites incorporated many improved features and performed so well that they later became the model and were adopted for all U.S. civil and military low-altitude meteorological satellites.

> **POLAR ORBITING SATELLITES:** There are two polar orbiting satellites in north-south orbits that observe the same spot of Earth twice daily, once during the day and once at night. Polar orbiting satellites provide imagery and atmospheric soundings of temperature and moisture data over the entire Earth. These satellites offer the advantage of operating closer to Earth (about 520 miles above the surface), providing detailed imagery, and excellent views of the polar regions.
>
> **GEOSTATIONARY SATELLITES:** Unlike polar orbiting satellites, geostationary satellites orbit at a much higher altitude of 22,236 miles above the Earth's surface, are positioned over the equator, and orbit around the Earth once every 24 hours. The satellite appears stationary relative to Earth allowing it to hover continuously over one position of Earth's surface. Because they stay above a fixed area on the surface, geostationary satellites provide a constant vigil for atmospheric "triggers" for severe weather conditions like tornadoes or hurricanes.

NRO'S TIROS DESIGN

TIROS was a 100-pound satellite shaped like a 10-sided polyhedron, 23-inches across and 21-inches high. A spinning motion, introduced when first launched into orbit produced around 12 revolutions per minute by small spin rockets. The spin axis was maintained perpendicular to the orbit plane by torqueing the satellite against the Earth's magnetic field; the force then created a direct-current loop around the satellite's perimeter. A ground command station would then direct the electric current to flow in the desired direction to generate the torque. The few NASA officials who knew about TIROS viewed the joint NRO-Air Force program as a no-risk test case of an "Earth-referenced" wheel-mode weather satellite.

DMSP SUCCESS

By mid-1965, NRO's "interim" weather satellites operated like a formal military space program. By then the DMSP provided the NRP with daily coverage over Eurasia and other territories using two polar orbit, sun-synchronous weather satellites. The program not only addressed the requirement to secretly surveil remote territories with excellent results but accomplished the mission at half the annual cost of NOMSS. In fact, DMSP pioneered weather satellite technology so well that the Department of Commerce embraced the initial DMSP wheel-mode Block 1 satellite, the TIROS Operational System (TOS), as an interim polar-orbiting weather satellite.

DMSP GROWING PAINS

Despite NRO's advances in meteorological technology, only five DMSP satellites were launched from May 1962 through September 1963 and several launches failed due to defective Scout rocket boosters. The first polar-orbiting satellite, viewed by the DMSP as a test, was a standard four-stage Scout booster carrying an NRO GRAB satellite, launched from Vandenberg Air Force Base. The test launch on 25 April 1962, ended in a Scout booster failure within sight of the ground station. The Scout booster failed again on 23 May when the vehicle self-destructed. The next DMSP launch on 23 August 1962 was a success though the ground-control team at first failed to track the weather satellite. By January 1964, the Scout boosters were replaced with Thor-Agena boosters and four DMSP satellites were successfully launched into orbit providing the NRP all of the meteorological data they needed. Despite setbacks, after DMSP acquired the Thor/Burner combinations in the ensuing months and years, they achieved an 86 percent launch success rate.


DMSP Block 1 Launch, 19 Jan 1964


DMSP Block 5D1, 11 SEPT 1976

SUCCESS WITH A PRICE

The DMSP-TOS under NRO became operational within 24 months and demonstrated impressive technical performance for strategic and tactical applications. Considering its cost and performance in the mid-1960s under NRP's umbrella, Commerce leaders told NASA they would adopt the DMSP wheel-mode spacecraft in place of NOAA's Nimbus weather satellite, to be used as the standard for low-altitude, polar-orbiting meteorological applications. That decision was formalized in the mid-1970s when the latest DMSP Block 5D, three axis-stabilized spacecraft was selected for civil programs. This prompted the declassification of the DMSP program in 1973. The choice to adopt a central satellite program to leverage related requirements for civil and military missions once again glossed over the national security aspects of why NRO leaders established the DMSP to begin with.

NASA POLAR-ORBITING ENVIRONMENTAL SATELLITE SYSTEM (NPOESS)

In May 1994, DoD, Commerce, and NASA released the NPOESS implementation plan endorsed by President William Clinton. The plan created an Integrated Program Office that developed, acquired, and operated all NPOESS systems. The NPOESS was comprised of senior officials from consolidated agencies to ensure requirements from each combined former organization were responsibly maintained under different elements of the NPOESS. NOAA was given oversight for the merged systems, including satellites on orbit and public representing the program to the civil and international communities. The DoD became responsible for contracting, acquiring, and launching new meteorological satellites. Reminiscent of the division of labor in 1961 that produced Nimbus, NASA assumed responsibility for development and acquisition of new cost-effective technologies related to the merged meteorological programs. DMSP's great success under NRO's stewardship skyrocketed the advancement of meteorological satellite technology for the nation, but also led to its termination. Nevertheless, NRO's significant contributions to weather satellite technology for both civil and military mission requirements cannot be overstated.

INNOVATIONS

RECONNAISSANCE

D-21 DRONE

D-21 Drone

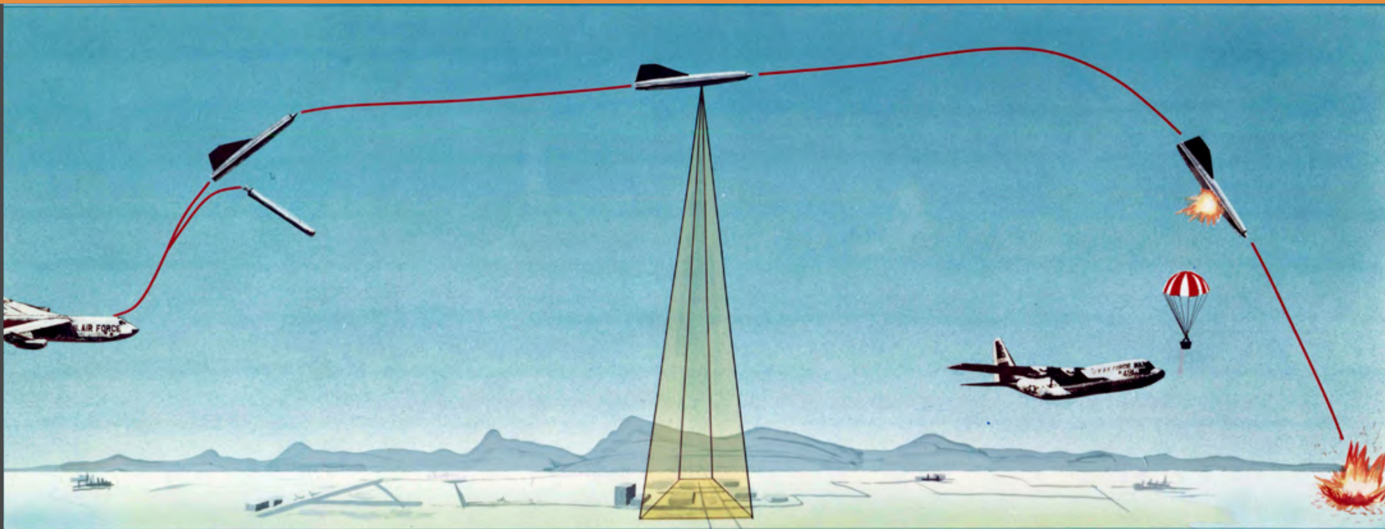
Drone Photo of Phoenix, AZ

D-21 DRONE

Decades before the advent of military and commercial unmanned aerial vehicles (UAVs), the NRO engineered, produced, demonstrated, and operationally tested a highly advanced, unpiloted, supersonic reconnaissance aircraft with unbelievable characteristics. This reconnaissance drone flew at speeds over Mach 3.3 at an altitude over 90,000 feet, and the NRO designed it using low radar observable technologies, suggestive of 21st century stealth technology. During the middle of the 20th century, the NRO and others had been conducting limited experimentation with drones, but it was the NRO's Program D that began experimenting with the development of the D-21 drone. The D-21 validated that unpiloted aircraft were possible and could have a role in reconnaissance. The NRO's work in the middle of the 20th century had anticipated what was to come, the proliferation of UAVs in the 21st century.

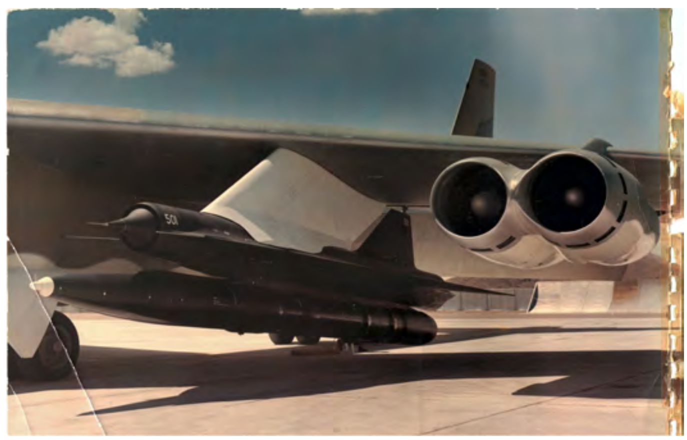
In October 1962, CIA authorized the Skunk Works, Lockheed's experimental engineering division, to study the feasibility of modifying the A-12 reconnaissance aircraft to carry and deploy a reconnaissance drone for unmanned overflight of denied areas. The mothership, renamed the M-21 to avoid confusion with the A-12, was fitted with a second seat for a launch control officer (LCO) for the drone, called the D-21. The M-21 Drone Program ended in 1966 after a crash that killed LCO Ray Torick. The Skunk Works built 38 drones.

From 1969 to 1971, the Air Force began using B-52s to launch some of the remaining drones against Chinese targets. The drones, re-designated as D-21B, flew four missions; none were completely successful. After the program was cancelled, one of the spare D-21B airframes (#538) was stored in California and then moved to the Aircraft Maintenance and Regeneration Center ("Boneyard") at Davis Monthan AFB near Tucson, AZ. In the 1990s, Warner Robbins AFB displayed and stored #538 until 2017, when it was transferred to the NRO. Eventually, the NRO entered into a loan agreement with the Southern Museum of Flight in Birmingham, Alabama. The museum restored and began displaying #538 in November 2018.



DESIGN SPECIFICATIONS:

Construction:	Titanium with small radar cross section
Dimensions:	Length—514.27 in Wing Span—288.90 in Height—85 in
Weight:	11,000 pounds, gross
Propulsion:	Marquardt Ramjet Solid propellant rocket booster
Performance:	Speed—Mach 3.25 Altitude—80,000 to 95,000 feet Range—3,000nm
Payload:	Hycon Frame camera (24" fl) Coverage: 28nm X 3020nm
Resolution:	1.5'
Mission Code Names:	TAGBOARD (D-21) SENIOR BOWL (D-21B)



B-52 with two D-21B drones under wings at top is a close up of D-21B on wing of a B-52.

DENIAL AND DECEPTION


Trojan Horse

Inflatable Tank

MYTHICAL DENIAL AND DECEPTION

Virgil in his *Aeneid* recounts the story of the Greeks carrying out a grand deception to defeat the city of Troy. The Trojans managed to stave off defeat for many years. After those many years, the leaders of the Greeks, as Virgil reports, decided to construct a large wooden horse to facilitate their deception—the horse was the emblem of Troy. After building the horse, the Greeks staged what looked like a retreat by sea, leaving the horse for capture by the Trojans. Assuming the Trojans would take their victory prize into the city, the Greeks hid a force inside the wooden horse. Consistent with their expectations, the Trojans seize the horse as a victory prize. Despite the warnings of the Trojan priest Laocoon to not seize the horse and bring it into the city, the Trojans did so. The Greek force waited until nightfall, then left the horse and opened the gates of the city. Troy fell to the Greeks and the war ended.

The story of the Trojan horse has traversed time to now symbolize acts of deception. Deception in conflict is a constant. The Cold War between the United States and the Soviet Union was no different. Deception and denial of truth and facts to hide activities are key strategies in waging war.

DENIAL AND DECEPTION IN WAR

There are many well-known deceptions in war. For example, the success of Allied troops against German forces occupying the shores of France during D-day was greatly enhanced by deception. The Allies created a fictional army to deceive the Germans into thinking that an attack to retake France would occur at other beaches than where Allied forces landed. To make the fictional army seem believable, the allies used inflatable devices to appear as tanks, trucks, and other equipment that would be necessary to support an army. With the inflatables in place in England, the Germans flew over and photographed the fake equipment, further enhancing the deception. When the Allied troops did attack on D-Day, the Germans remained convinced the attacks were a diversion from the real attack that would occur elsewhere on the French coast and with a more powerful force. The Germans held troops in reserve for the attack that never came, allowing Allied success on D-Day.

THE USSR AND DENIAL AND DECEPTION

The Soviet Union adopted a military strategy of denial and deception developed by the Tsarist Army in the early 20th century where an army deception school developed the doctrine. The formal doctrine became known as maskirovka, meaning either disguise or masking.

As the Cold War progressed, the Soviets relied on denial and deception frequently. One of the earliest deceptions was carried out between 1954 and 1955. By the mid-1950s the U.S. had developed long-range bombers that could be used to carry out a nuclear attack against the Soviet Union. The Soviets did not have a similar capability, but wanted the world to believe they did. In winter 1954, Aviation Week carried a story describing the Soviets' development of their own long-range jet powered bomber, the Myasishchev M-4 Molot, or hammer in Russian. The bomber was designated Bison by the West, and made its first appearance at the 1954 May Day celebrations in Moscow.

WEATHER
Forecast for Tucson: Clear, little change.
Temperatures
Yesterday: HIGH 85 LOW 51
Year Ago: HIGH 81 LOW 55
U. S. Weather Bureau

The Arizona Daily Star

★ An Independent NEWSpaper Printing The News Impartially ★

FINAL
EDITION
TEN CENTS

VOL. 121 NO. 296 TUCSON, ARIZONA, TUESDAY MORNING, OCTOBER 23, 1962 THIRTY PAGES

U.S. BEGINS BLOCKADE OF CUBA; GRIM WARNING ISSUED TO RUSSIA

Himalayan Battling Worsens

New Front Opened By Chinese Reds

The President And Cuba

(An Editorial)

The distinctive feature of President Kennedy's address to the nation concerning the development of intermediate and long-range missile sites in Cuba, is that it represents a determined and uncompromising effort to persuade the Soviet Union to abandon its military threat in Cuba.

Air Force, Navy Men Hopping

Planes And Warships Busy In Florida Area

President Says Soviet Lied, Castro Missile Bases For Offense

Washington, Oct. 22 (AP)—President Kennedy put into effect

Each year, the Soviets staged a large military air show at the Tushino airfield near Moscow. At the 1955 show, the Soviets knew that western military attaches would attend the show. Building on what was already known about the M-4, the Soviets flew 10 bombers in a dramatic display. Nine then quickly turned around out of site of the observers and were joined by eight more bombers. This left the impression that the Soviets had produced 28 bombers in a year, instead of 18, or at a third higher rate than they actually produced the bombers. Based on this observation, U.S. military analysts concluded that the Soviets would outpace U.S. strategic bomber production by the early 1960s, creating a "bomber gap" between the two adversaries. Word of the analysis became public knowledge, creating a furor in political and military circles.

In October 1962, U.S. U-2 overflights of Cuba captured telltale signatures of Soviet nuclear weapons placement in Cuba. The Soviets carried out a number of deceptions to get the missiles and many thousands of troops into Cuba to build and maintain the missile launch facilities. For example, the name chosen for the operation led western analysts to believe that the activity was being carried out in an artic location versus the warm Caribbean climate. The missiles and equipment were covered with shrouds to hide them from any aerial observation of the ships carrying them. The ships were unloaded at multiple ports in Cuba, making it difficult to observe the massive amount of material and personnel moved into Cuba. Just weeks before the U.S. discovered the Cuban missile deception, the Soviet Union's ambassador assured the U.S. Attorney General and brother of the U.S. President that no troops or offensive weapons were or would be placed in Cuba by the Soviets. Even after the discovery of the emplacements, the Soviet Union went to great lengths to deny their existence despite conclusive imagery intelligence disclosed to other world leaders and the public.

In August 1968, the Soviet Union led an invasion of Warsaw Pact member Czechoslovakia to remove a government that was pursuing very liberal reforms, threatening what counted for Communist orthodoxy at the time. For example, the Soviets ordered Warsaw Pact troops to remain in barracks and also remove material that led the Czech leadership to believe there was not an imminent outside threat. Instead, the Soviet Union and other Warsaw Pact nations were able to move troops and supplies to the Czech border in advance of the rapid and overwhelming invasion of Czechoslovakia. The surprise allowed the Soviet Union to depose the more liberal government and replace it with a government that would toe the Soviet line.

U.S. RESPONSE TO SOVIET DENIAL AND DECEPTION IN THE COLD WAR

The U.S. invested significant resources into developing sophisticated technological means to understand the true intentions of the Soviet Union and unmask their deceptions. The U-2 played an early and important role in this effort. For example, the U-2 captured an image of a Soviet airfield that displayed their entire M-4 Bison bomber fleet. There were far fewer aircraft than the Tushino deception had led U.S. military analysts to believe existed. Concrete intelligence dismissed the "bomber gap."

After the 1957 launch of the Soviets' Sputnik satellite, many in the U.S. grew very concerned that the Soviet Union was outpacing the U.S. in the development of ballistic missiles—missiles that could deliver nuclear bombs to the U.S. By August 1960, the U.S. successfully launched a Corona satellite that set the course for the U.S. to obtain concrete intelligence dispelling such a "missile gap" existed. By fall 1960, the Corona imaging capability countered Soviet efforts to leave the impression they were outpacing the U.S.

In September 1961, the Kennedy administration established the National Reconnaissance Office to develop even more sophisticated reconnaissance satellites to counter Soviet denial and deception. The first photoreconnaissance satellite launched by the newly formed NRO was the 1963 Gambit high-resolution satellite. The Gambit program would eventually produce a second-generation satellite that could capture images of objects smaller than one foot in size. This level of resolution made it much more difficult for the Soviet Union to carry out denial and deception activities.

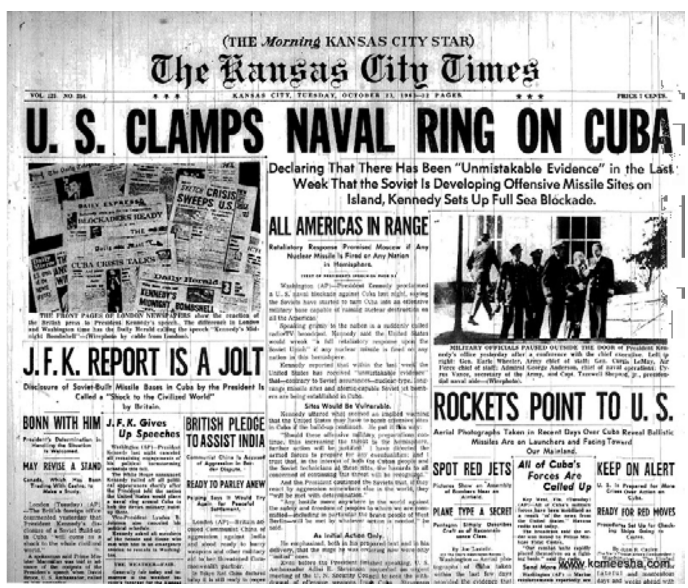
In 1964, the NRO developed a satellite specifically to test technology that could directly challenge denial and deception activities. The program, known as Quill, was to launch an experimental satellite that would test whether or not radar from space could be processed into images. The Quill experiment confirmed radar could be used to obtain imagery from space—a capability that would allow the United States to obtain reconnaissance imagery under conditions used by the Soviet Union to disguise and obscure their strategic and tactical activities.

To gain greater persistence, the NRO developed a large satellite, Hexagon, that carried 60 miles of film stock. Hexagon allowed the U.S. to repeatedly capture imagery of the Soviet Union and other areas of concern using its broad area coverage cameras. Hexagon's repeated and persistent imagery made it much harder for the Soviets to carry out denial and deception activities.

While the U.S. was developing photoreconnaissance satellites, it was also developing signals collection satellites. The world's first reconnaissance satellite was an experimental satellite known as GRAB. It proved to be highly successful, giving the U.S. the most comprehensive understanding of Soviet radar capabilities to date—an understanding necessary to carry out a nuclear counterattack by evading those radars. After GRAB began collection of signals from space, the U.S. launched many other experimental Sigint satellites, demonstrating means to collect communications signals, as well as signals associated with Soviet military equipment, launch vehicles, and other systems that posed a threat to the U.S. They lifted the veil further, exposing true Soviet intentions and capabilities.

By 1976, the NRO launched the first electro-optical satellite, known as Kennen, which could collect imagery in near real-time and remain in orbit much longer than the film return systems. With this enhanced capability, the Soviet Union had even less flexibility in carrying out denial and deception activities given the increased persistence of U.S. imagery collection capability.

Although little can be said of more recent NRO capabilities for countering U.S. adversaries' denial and deception activities, the earlier declassified history demonstrates a regular and ever more sophisticated capability of the NRO to collect intelligence countering denial and deception. The innovation of the NRO and the innovators who pressed the best technology into service provided formidable means for countering denial and deception—a responsibility that continues today.



(THE *Morning* KANSAS CITY STAR)

The Kansas City Times

KANSAS CITY, TUESDAY, OCTOBER 23, 1962

U. S. CLAMPS NAVAL RING ON CUBA

Declaring That There Has Been "Unmistakable Evidence" in the Last Week That the Soviet Is Developing Offensive Missile Sites on Island, Kennedy Sets Up Full Sea Blockade.

ALL AMERICAS IN RANGE

Retaliatory Response Promised Moscow if Any Nuclear Missile Is Fired or Any Nation in Hemisphere.

J.F.K. REPORT IS A JOLT

Disclosure of Soviet-Built Missile Bases in Cuba by the President Is Called a "Shock to the Civilized World" by Britain.

ROCKETS POINT TO U. S.

Aerial Photographs Taken in Recent Days Over Cuba Reveal Ballistic Missiles Are on Launchers and Facing Toward Our Mainland.

BONN WITH HIM

MAY REVISE A STAND

J.F.K. Gives Up Speeches

BRITISH PLEDGE TO ASSIST INDIA

READY TO PARLEY ANEW

SPOT RED JETS

PLANE TYPE A SECRET

All of Cuba's Forces Are Called Up

KEEP ON ALERT

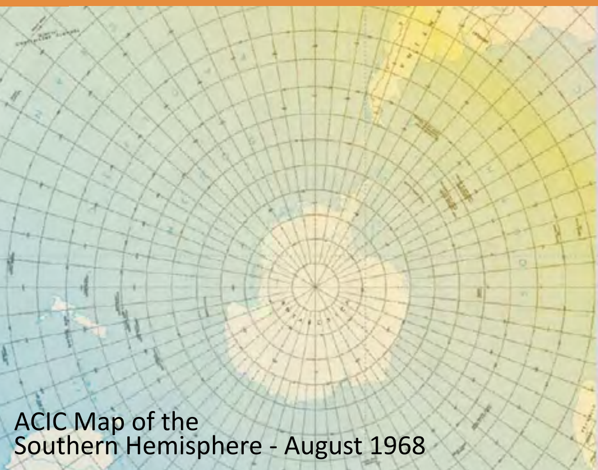
READY FOR RED MOVES

Sites Would Be Vulnerable.

As Initial Action Only.

www.kcmeesha.com

GEODETIC DATABASES



ACIC Map of the Southern Hemisphere - August 1968

In the 1960s, the Intelligence Community faced two distinctly different mapping situations — the lack of mapping data of the Soviet Union and the relatively good mapping data of the United States. The imagery collected by two NRO satellite systems—Corona (operational life 1960-72) and Argon (1961-64)—revolutionized U.S. mapmaking activities concerning features on the Earth's surface and eventually led to the development of technical applications for a geodetic database framework. The task for mapmakers was to find a technical solution to compile the imagery data into that geodetic database. Three military mapping organizations would take on the technological challenge of mapping the Soviet Union: the Air Force Aeronautical Chart and Information Center (ACIC) in St. Louis, MO, and the Army Map Service (AMS) and Navy Hydrographic Office (NHO), both in the Washington, D.C. Metro Area. Federal civil agencies would take on the challenge of updating U.S. maps.

MAPPING THE USSR — MILITARY MAPPING AGENCIES

During the 1950s, a "Cartographic Iron Curtain" prevented the U.S. from creating accurate maps of the Soviet Union. The lack of basic maps of the USSR existed before the Cold War. Large areas of the country had never been mapped, and during the Cold War, several roadblocks made mapping the USSR difficult. The closed Soviet society kept strict controls on and added distortions to all detailed mapping data, and there was a concerted deception program directed at foreigners who used generalized maps released by the Soviet Union.

Corona and Argon imagery provided the key to break through the USSR's Cartographic Iron Curtain. Corona's higher resolution imagery yielded detailed information, and Argon's low resolution provided essential data for improving the accuracy of the geodetic framework. Intensive technical efforts of the U.S. military mapping organizations and integration of the satellite imagery armed the three military mapping agencies with the tools to build a geodetic framework of the Soviet Union. Each organization would take on different aspects of the obstacles to mapping the country.

The Air Force Aeronautical Chart and Information Center focused on the development of a worldwide geodetic network. Its program focused on analysis, integration, and triangulation used in orbital positions of the Corona and Argon spacecraft at the time of imaging to obtain a steadily increasing geodetic accuracy that was critical in supporting bombing and missile targeting in the event of U.S. - Soviet hostilities. Corona's wide - area coverage capabilities enabled production of air navigation charts, which were important for potential targeting areas.

The Army Map Service exploited satellite imagery to produce more reliable depictions of all ground features of the USSR, a difficult and time-consuming project. The objective was to cover the entire USSR landmass, supplemented by areas of high interest and larger scales for major cities. To achieve this, a crash program produced hypsometric maps (with contour and elevation data) and planimetric maps (without terrain elevation).

Due to an aggressive Soviet threat, the Army Chief of Staff for Intelligence and the CIA developed a joint mapping program — the Special Intelligence Graphic (SIG) — to help reduce production times. SIG data responded to military and intelligence requirements. The AMS concentrated on the basic map framework, and the CIA Directorate of Intelligence provided research assistance in identifying and annotating manmade features. A prototype map sheet of Stalingrad was used to test the joint production program. The success of the prototype led to mapping the entire USSR and, eventually, to mapping China and adjacent areas in Eurasia.

The Navy Hydrographic Office had a smaller role in the exploitation of satellite imagery. However, the NHO was able to use Corona and Argon imagery to update its nautical charts around the world.

The work of these agencies was key to producing reliable maps, charts, and geodetic data to meet needs on the Soviet Bloc, as well as navigation chart requirements on a worldwide basis. Completed in just a decade, the accurate mapping database covered the entire Soviet landmass (almost one-sixth of the Earth's land surface) and was vital to the National Technical Means used to enter arms control agreements between the U.S. and Soviet Union.

MAPPING THE U.S. – FEDERAL CIVIL AGENCIES

Use of Corona imagery began in the late 1960s with an initiative by President Johnson's Science Advisor to test the value of overhead satellite imagery for U.S. civil purposes. The U.S. Geological Survey opened a classified facility for access to civil agencies to exploit the Corona imagery for various mapping, research, and other production programs.

The use of satellite imagery for domestic purposes would have a different focus, but was no less urgent, than mapping the Soviet Union. Accurate maps of the U.S. were available and the basic geodetic control framework existed, but they were outdated. What did not exist was the technology needed to create more detailed large-scale maps. These updated U.S. maps were needed, due to the postwar expansion of urban core areas and expanding suburbs, and the extensive construction of interstates and highways. The Department of Agriculture's Forest Service updated its maps of national forest lands, and the National Oceanic and Atmospheric Administration corrected and updated its nautical and aeronautical charts. The Environmental Protection Agency used Corona imagery to find areas impacted by pollution.

CONCLUSION

Within a decade, the U.S. had mapped the USSR at a medium scale and laid the groundwork for the future of U.S. mapmaking activities. These early mapping activities met critical national security needs, as well as civil domestic requirements. Success would have been unreachable without the expertise of specialists in photointerpretation, photogrammetry, geodetic science, and Russian language skills, as well as enormous investments in research and development of unique production equipment, all supported by complex computer programs. The concerted effort from the three military organizations to create an accurate geodetic database largely from NRO satellite imagery led to changes in the organizational structure of the U.S. military mapmaking organizations. The consolidation of the three mapping agencies, first begun as early as the 1970s, would eventually produce today's National Geospatial-Intelligence Agency (NGA).

STEALTH AIRCRAFT


U-2


SR-71


D-21


A-12

BANDITS IN THE NIGHT

In the early morning hours of 20 December 1989, two F-117A Nighthawk stealth fighters each dropped single 2,000-pound Mark 84 bombs onto Rio Hato Airfield, 120 km southwest of Panama City, in the opening hours of the U.S. invasion of Panama. This was the first use of stealth aircraft in combat, six years after the F-117A was declared operational, and more than a decade since the decision had been made to build the world's first stealth combat aircraft. However, that decision would never have been made had it not been for significant advances in stealth technology developed by Lockheed Martin and the NRO.

TRYING TO HIDE THE U-2

In 1956, despite assurances from his senior intelligence advisors that the U-2 would be virtually undetectable to the Soviets, President Eisenhower was upset when he learned that Soviet early warning radars had tracked the first U-2 flights over the Soviet Union. Eisenhower ordered a temporary halt to U-2 flights, and designers got busy trying to find ways to reduce the radar cross section (RCS) of the U-2 airframe. Later that year, engineers installed fiberglass rods to the non-moving parts of the wings and surrounded the airframe with a small-gauge wire with precisely spaced ferrite beads. The wire and beads were supposed to capture incoming 70-MHz radar pulses and either trap them in the loop or weaken them so much that they would not register as a valid radar return. A second approach, tested in early 1958, involved the use of plastic material containing a printed circuit designed to absorb radar pulses in the 65- to 85-MHz range glued to outside parts of the fuselage. Although these approaches had some success, they did not protect against radars outside of that narrow range of frequencies. More importantly, they degraded the performance of the aircraft, forcing it to fly at a lower altitude and even causing some engine problems, one of which resulted in the death of a Lockheed test pilot. However, the concepts were not lost, and the idea of adding radar-absorbing material to the outside of the aircraft's fuselage proved to be an effective strategy used later with the F-117A and many future stealth aircraft.

SHIELDING THE OXCART

In late 1957, an advisory committee selected to choose a design for a replacement of the U-2 was formed by Dr. Richard Bissell, the CIA's U-2 project manager and soon-to-be co-Director of NRO. In contrast to the U-2, design of the A-12 centered as much on a minimal RCS as it did on aircraft performance. Over the next two years, Lockheed and Convair submitted proposal after proposal, but all were rejected. In August 1959, the committee finally chose the latest Lockheed design (the A-12), based as much on Lockheed's history with the U-2 program, as on their design of the A-12. However, the committee was still not happy with the level of RCS exposure in the proposed design and required Lockheed to reduce it even further before a full contract was awarded.

Clarence "Kelly" Johnson, the Lockheed mastermind behind the U-2 and A-12 designs, incorporated several ingenious technologies to reduce the RCS of the A-12, such as a continuously curving airframe, a fore-body with tightly slanted edges called chines, engine housings (nacelles) located mid-wing, canted rudders, and nonmetallic parts. A cesium fuel additive was added to reduce the radar detectability of the afterburner plume. To reduce radar reflections, the two canted rudders were fabricated from laminated nonmetallic materials—the first time these materials were used to build an aircraft. Later, the production aircraft was painted with a radar-absorbent coating of ferrite particles in a plastic binder. There was little difference in the RCS design between the A-12 and SR-71, other than the SR-71 was larger with a more prominent nose and body chines. However, while the SR-71 was larger and presented a bigger radar target, it also carried a number of electronic countermeasure systems that the A-12 did not have, which greatly enhanced SR-71 electronic defenses.

D-21 DRONE

Began in the early 1960s by NRO's Program D, the D-21 was a ramjet-powered pilot-less drone designed to be launched from the back of a modified A-12 and fly even higher and faster than the A-12. After a fateful accident involving one of the modified A-12s, the design was altered to be launched from under the wing of a modified B-52, which was less dangerous to the carrier aircraft. The D-21 drone incorporated many design features of the A-12, including the use of non-metallic components and insulated fuel propulsion parts to help reduce infrared detection. However, after several test flight failures and the drone's mission becoming less essential, the program was cancelled in 1971.

LONG-TERM BENEFITS

Although much of the work that NRO and Lockheed carried out in the 1960s saw few operational results, it was not wasted effort. Although the A-12 was identified and fired at a few times over North Vietnam in its short operational history, it did successfully complete some missions where it was not detected. More importantly, the seeds of research that the engineers planted in the 1960s finally bloomed in the 1980s, when many of their designs were successfully incorporated into the world's first stealth combat aircraft. Today's stealth aircraft continue to utilize the ideas of advanced structural designs, composite components, radar absorbent paints, and diffused exhaust vents. Even the Space Shuttle applied the concept of heat absorbing tiles to diffuse the intense heat of re-entry which, while not a stealth concept, originated from the idea of applying radar-absorbing materials to an aircraft. As with many NRO scientific breakthroughs, many of these design elements are still being utilized today, long after the mission they were designed for has ended, to benefit additional NRO programs, U.S. national security, and the American people.

INNOVATIONS

COMMERCIAL APPLICATIONS

BATTERY DEVELOPMENT


NiH2 Battery

EARLY BATTERY TECHNOLOGY

At the turn of the 20th century, batteries first emerged as a source of energy to power new tools and devices invented in the early industrial era. Alkaline electrolyte batteries promised early commercial application. By the 1930s and 1940s new alkaline batteries such as zinc–silver oxide and zinc–mercuric oxide alkaline batteries significantly improved battery performance. In the latter half of the 20th century, new advances and materials resulted in smaller and more powerful batteries for use in portable equipment. The more recent development of batteries using lithium, nickel-hydrogen, and nickel–metal hydride have opened new applications in commercial markets such as electric vehicles, cell phones, and computers, as well as applications in spacecraft.

ORIGINS OF POWERED SATELLITES

Science fiction writer Arthur C. Clarke may have been the first to propose the basic idea of a satellite and its varied uses. Even before World War II was over, Clarke speculated how one might use the German V-2 as a satellite launch vehicle. In the February 1945 edition of Wireless World Clarke wrote,

> A rocket which can reach a speed of 8 km/sec parallel to the earth's surface would continue to circle it forever in a closed orbit; it would become an 'artificial satellite'.... It would thus be possible to have a hundred-weight of instruments circling the earth perpetually outside the limits of the atmosphere and broadcasting information as long as the batteries lasted. Since the rocket would be in brilliant sunshine for half the time, the operating period might be indefinitely prolonged by the use of thermocouples and photo-electronic elements.

Clarke anticipated the idea of using geosynchronous satellites for receiving and retransmitting radio signals from space—the basic concept for both a communications satellite and a satellite for collecting Sigint. He observed that

> An 'artificial satellite' at the correct distance from the earth would make one revolution every 24 hours; i.e., it would remain stationary above the same spot and would be within optical range of nearly half the earth's surface. Three repeater stations, 120 degrees apart in the correct orbit, could give television and microwave coverage to the entire planet.

BATTERY USE IN SATELLITES

Long-time battery manufacturer Saft explains,

> On satellites, batteries are used to provide power at "night," when the satellite passes behind the Earth and is no longer illuminated by the Sun. In the "day" phase, energy is produced by solar panels, which recharge the batteries. Using the power of the sun in this way is very important because it gives the batteries a long operating life. Batteries designed for space must meet a unique set of demands: they must be reliable, have an operating life of more than 20 years, and be able to withstand extreme temperatures and radiation. They must also be strong enough to survive launch vibrations, landing impact, and other physical shocks.

Early NRO satellites had relatively short design lives of a few days' or weeks' duration. This allowed the satellites to carry batteries that sustained the mission of the satellite. As NRO satellites became more sophisticated, they required rechargeable battery systems, frequently relying on solar cells to recharge the battery. Low earth orbit satellites are shadowed by the Earth requiring battery power. Satellites in other orbits also experience "eclipse periods" requiring battery power.

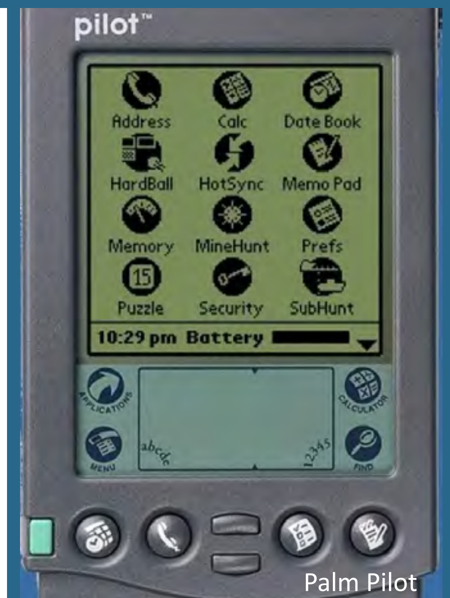
As with all satellites, batteries for NRO satellites are designed considering a number of factors including battery capacity and voltage, discharge and charge rates, and methods of charging. Launch stresses and the space operational environment present a number of factors for battery design including temperature fluctuations, vibration, and shock stresses.

NRO INVESTMENT IN BATTERY TECHNOLOGY

The NRO has done research on many space power storage and control projects through the years. Nickel-cadmium (NiCd) space batteries, which had been the standard for many years, largely moved to nickel-hydrogen (NiH2) batteries because of pioneering work by the NRO. The NiH2 single pressure vessel (SPV) battery was developed at Johnson Controls by the NRO. This battery was also used widely on commercial spacecraft, including IRIDIUM for example. Additionally, the NRO has supported research on NiMH (Nickel Metal Hydride) batteries for space application. The NRO has supported development of Lithium technology batteries for use in space applications that are used widely in everything from cellular phones to other computing devices.

CELLPHONE DEVELOPMENT


1980s Cellphone



Palm Pilot

COMMUNICATING ON THE GO

Occasionally an older movie will show a scene where an actor is in a car and picks up a telephone handset—similar to what would have been in homes and offices at the time—and speaks to another person. These early communication devices were not cell phones; instead they were powerful two way radios often used by first responders and fleets such as taxi services. They are known as 0G or Zero Generation mobile networks. The first generation developed using cellular technology or towers that covered a geographic area close enough to another coverage area—or cell—that the signal could be handed from one cell to the next during travel. By the end of the 1970s, the first mobile cellular network appeared in Japan, followed by European and U.S. cellular networks in the early to mid-1980s. These 1G or first generation cell phones worked on limited analog signal networks and were very costly.

By the early 1990s, cellular companies began constructing networks using digital signals. European providers developed the Global System for Mobile Communications or GSM standard. The use of a common standard marked the beginning of the 2G era. By the mid-1990s, Qualcomm offered Code Division Multiple Access or CDMA as a communication standard that offered more efficient use of cellular bandwidth. Roughly a decade later, providers upgraded their systems to 3G standards that enabled not only communication using cell phones, but early availability of information search and retrieval. By the end of the 2000s, 4G technology enabled greater access to the World Wide Web necessitated by growing use of the internet for multiple activities and services. And then a decade later, 5G technology promised more capacity and speed for cellular users who are highly dependent upon mobile devices for communication, social interaction, and commerce.

SMARTPHONES BECOME ESSENTIAL

Recognizing that technology enabled mobile devices to do more than allow users to call and text, engineers developed phones that could carry out a number of additional functions. An IBM engineer developed the first such device, the Simon Personal Communicator, sold by BellSouth beginning in 1994. At the same time cell phones were emerging as consumer products; companies like Palm Inc. created Personal Digital Assistants that allowed users to maintain calendars, address books, To Do lists, and other functions for life at home and at the office. Finally, companies like Apple developed digital products like the iPod for storing and playing music and other media.

Mobile device manufacturers recognized the benefits of combining the functions of cellphones, PDAs, and portable media players into a single device. The earliest of these products were developed by companies such as Nokia and Ericsson who dominated the manufacturing of cellphones in the late 1990s and early 2000s. The introduction of

3G technology fueled the development of such devices. Research in Motion introduced their Blackberry mobile device in 2002 that allowed users to email, send wireless faxes, and browse the internet. Blackberry would evolve as the dominant device for such purposes in the 2000s.

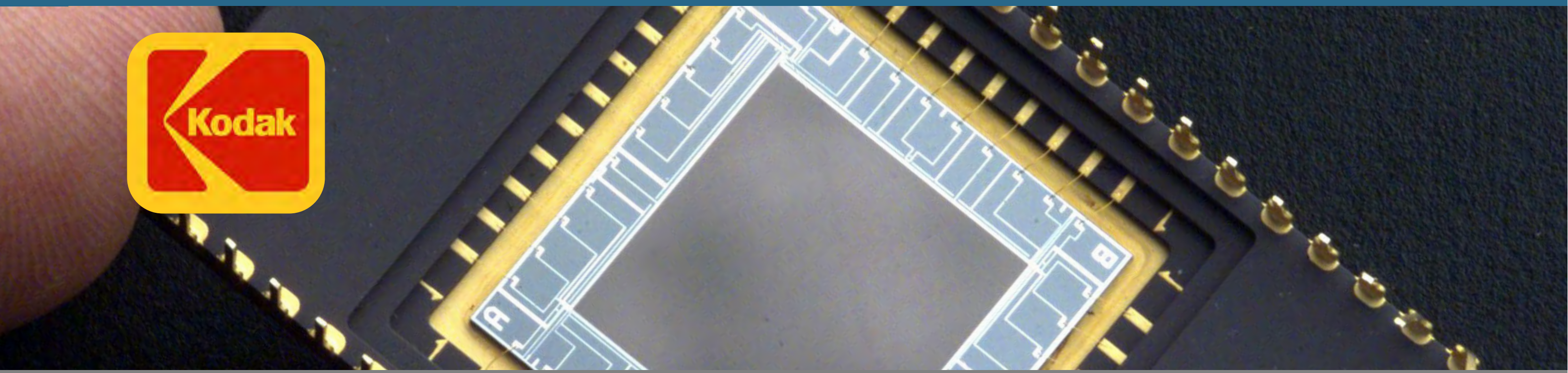
In 2007, Apple Corporation's Steve Jobs introduced the first Apple iPhone that redefined mobile devices. The iPhone had a touchscreen, eliminating physical keyboards used by other devices. It also included a camera for taking photographs, music storage and playback, and personal planning capabilities found in other mobile devices. Shortly after the release of the iPhone, Apple unveiled the App Store where users could purchase applications for use on their devices. Apple would continue to refine the iPhone series, making it one of the dominant manufacturers of smartphones today.

Other companies recognized that mobile devices would become essential to everyday lives of consumers. In 2003, software engineers established the Android Corporation for developing an operating system for mobile devices. After struggling, Google purchased the company in 2005, forming the foundation for Google to enter the mobile device marketplace. Using the open source Linux operating system as the foundation, Google released the Android mobile operating system in 2007 for use by cell phone manufacturers, with the first commercial device using the system released in 2008. Unlike Apple, Android did not initially release its own hardware, only doing so in 2011. Although consumers were slow to adopt Android in the early years, the operating system became dominant within a decade. Others who developed mobile operating systems prior to Android, such as Microsoft and Research in Motion, ceased developing their systems in favor of Google's Android.

THE NRO AND CELLPHONE TECHNOLOGY

Today's cellphone is more than a device to make calls on the go. It is a navigation device, camera, media player, productivity device, research device, activity tracker, multi-platform communication device, and much more. The NRO has nurtured many of the technologies that are integrated into the cellphone. Because of intelligence needs, the NRO was an early developer of databases and technology to locate objects and locations on Earth with precision. The NRO invested in the development of high density batteries that could be recharged multiple times. The organization pursued the development of signals that could carry information in a more efficient manor to enhance use of available bandwidth. The NRO developed a major digital camera system for use in space that fundamentally altered the capture, processing, and use of digital images. Recognizing that touchscreen technology enhances the use of technology products, the NRO invested in early development of touchscreens. These and other investments have spurred along an industrial base that continues to refine consumer products like the smartphone—altering the way people go on about their daily lives.

CHARGE-COUPLED DEVICE



HUMAN QUEST FOR IMAGERY

From their earliest days, humans have captured images of their world as they knew it. Early in 2021, archeologists announced that they had identified the oldest drawing to date in a cave on the remote Indonesian island of Sulawesi. The image was first found by a doctoral student in 2017 and dated back to 45,500 years ago. The image was a life-sized picture of a pig.

In the millennia since, human imaging has progressed from drawings and carvings largely preserved in caves to paintings, portraits, and photographs housed in museum galleries. In accordance with this progression, those who create images have developed tools that increased the complexity and accurate capture of the image's subject. Sophisticated and advanced satellite imagery has been a direct beneficiary of human progress in image capture.

ORIGINS OF PHOTOGRAPHY

Most discussions of the origin of photography acknowledge that the word is derived from the Greek *photos* or light, and *graphein* or to draw. The origins of capturing images reside in early efforts to cast light to produce images. For instance, the use of a camera obscura to cast an image from outside a room onto a wall inside the room using a small hole or lens can possibly be traced back more than two millennia. Early efforts in using materials to capture images such as Heinrich Schulze using salts and sunlight or Nicephore Niepce using bitumen and lavender oil to copy drawings are examples.

Louis-Jacques-Mande Daguerre, collaborating with Niepce, created the first images that would be recognized as photographs. He created the daguerreotype by first discovering a process using iodized silver to capture an image on glass and then using a sodium solution to fix the image on the glass. Others such as Hercules Florence and William Henry Fox Talbot worked on processes to fix images to paper.

By the mid-1800s, the daguerreotype became a global means for capturing and preserving images. Talbot continued to refine his efforts to preserve images on paper. Richard Leach Maddox developed a process for capturing images on a "dry plate" or one that used a gelatin mixture instead of liquid to capture images. By the end of the 19th century, photography became more common and convenient because of these advancements.

Just prior to the turn of the 20th century, George Eastman invented first a paper-based film and then a celluloid film base. This, in conjunction with the Kodak cameras he developed, opened the world to widespread photography. The introduction of 35mm film for photography in the early 20th century further enhanced use of cameras by a wider segment of the world's population—a trend that would continue until the end of the 20th century.

PHOTOGRAPHY FROM SPACE

During the early years of the Cold War between the United States and the Soviet Union, the U.S. faced great difficulty in understanding the actual military threat from the USSR. Because the Soviet Union closed its borders and heavily controlled movements of foreign nationals who visited, the U.S. could not depend on human sources for intelligence. The 1957 launch of the Soviets' Sputnik satellite demonstrated launch capability that could be used to fire a nuclear-armed missile against the United States.

In order to gain insight into Soviet military capabilities, the U.S. turned to developing technology for obtaining intelligence. A mainstay of this emerging capability was the development of satellites for collecting imagery using space-based cameras.

In August 1960, the U.S. obtained its first imagery of the Soviet Union using a Corona photoreconnaissance satellite. Within months, the Corona satellites confirmed the U.S. maintained an advantage in the number of nuclear-armed intercontinental missiles. This opened up a critical source of intelligence for the United States.

The Corona satellite captured images on film. Once the film supply was exhausted, the captured images were returned to Earth in film return vehicles. Eastman Kodak processed the film at a special facility, providing the Central Intelligence Agency this new critical source of information. In 1963, the Gambit photoreconnaissance satellite joined Corona, taking high-resolution images of specific areas identified from Corona's broad area search capability. In 1971, the Corona system was further supplemented and later replaced by the film return Hexagon system that carried significantly more film and thereby had more capability.

CRISIS IMAGERY NEED

While Corona, Gambit, and Hexagon proved highly effective for obtaining insight into Soviet strategic weapons capabilities, they were less useful for managing U.S. responses to international crises. None of these systems were on-orbit continuously, and they could not be launched rapidly in response to a crisis. Additionally, the film from the systems was not returned for days or weeks, leaving them unable to provide timely intelligence.

The United States needed a new imaging technology for crisis imagery—one that was not available commercially. In 1969, two Bell Labs scientists, Willard Boyle and George Smith, were engaged in developing better computer memory by sequencing metal oxide semiconductor (MOS) capacitors. They found that radiation disrupted the MOS capacitors in series for memory, but their sensitivity to light radiation turned out to establish a basis for capturing a digital image.

Boyle and Smith assembled the MOS array and discovered that the device was sensitive to light photons and that they could scan the electron charge taken up by the capacitors associated with light. By scanning this array, they could create a camera that produced digital images. By 1971, they produced a camera sensor using this approach, which became known as a charge-coupled device. The world now had a cutting-edge possibility for capturing digital images.

DIGITAL IMAGERY FROM SPACE

At the same time Boyle and Smith were developing the CCD, the National Reconnaissance Office was searching for a solution for obtaining crisis imagery. In the late 1960s, the Air Force program at the NRO proposed to scan the film on the Gambit vehicle before deorbiting it and transmitting those images back to Earth. The U.S. had attempted scan readout from space in the early 1960s, but the technology failed to work as needed. The NRO also explored the possibility of always having film-return systems ready to launch quickly to obtain crisis imagery. This approach was very costly.

Engineers and scientists in the CIA program at the NRO followed the developments in digital photography. They saw the emerging digital technology, such as photo transistors, photo diodes, and the CCD, as potential solutions for building a satellite optical system that could obtain imagery from space. The NRO established a new program office to develop an electrical optical satellite, known as Kennen, using one of these technologies. One bidder proposed using photo transistors while another proposed using photo diode arrays to capture digital images from space. Eventually the Kennen program leadership utilized the existing technology before later adoption of CCDs to improve imaging quality.

Back on Earth, CCDs would emerge by the early 1980s as a key technology for digital photography. Several companies worked on improvements to and commercial applications for CCDs. Fairchild Semiconductor developed by the mid-1970s a CCD for potential commercial use. Integrating that CCD, Kodak developed the first still camera in 1975. Kodak would wait nearly 20 years before introducing a commercial camera using CCDs. As the century turned, major camera manufacturers developed cameras to take digital images, many using the CCD.

The NRO's Kennen system first orbited in 1976. It opened a new era in imaging capture. By 1986, the NRO stopped using film return systems and became fully dependent upon digital imagery enabled by CCDs. Although at least a decade ahead of commercial CCD use, the NRO's investment in CCD technology provided considerable resources for advancing digital image capture. The innovation of the NRO in image capture technology opened new possibilities for recording important events in human history—a human quest that goes back at least 45,000 years.

CHANGE DETECTION

Caspian Sea Monster

CORONA BASELINE

In August 1960, the U.S.'s first successful photoreconnaissance satellite, Corona, opened new opportunities to visually detect changes in intelligence targets. Corona's first intelligence image captured the USSR's Mys Shmidta air base on the extreme northeast coast of that large nation, just 400 miles distant from Nome, Alaska. The air base was one of a group constructed by the Soviets in 1954 for use by long-range bombers capable of nuclear attack on the United States. Understanding developments and changes at Mys Shmidta and other airbases was critical to assess the USSR's advancements in nuclear first-strike capabilities.

With the establishment of the NRO in 1961, the United States continued to develop more capable imagery systems, such as the Gambit high-resolution photoreconnaissance satellite that enhanced intelligence analysts' ability to detect changes in locations such as Mys Shmidta. These earliest examples of change detection efforts, illustrate the new capability that emerged from the U.S.'s first successes in obtaining overhead intelligence.

THE MYSTERY OF THE "CASPIAN SEA MONSTER"

Often imagery analysts would uncover objects captured by NRO satellites that had no immediate explanation. On one occasion, an analyst discovered a mysterious, large craft in an image of the Caspian Sea shoreline. It appeared to be an aircraft with stubbed wings, new to the Soviet arsenal. Intelligence nicknamed the craft the "Caspian Sea Monster," and for many years, the NRO imaged this location to figure out what it was designed to do, using Corona and Gambit satellites, as well as Corona's successor, Hexagon.

After noting changes, analysts were able to conclude it was a large hydrofoil, a cross between a boat and plane designed by the Soviets to fly a few meters above the sea's surface. It could carry massive numbers of men or amounts of material at nearly 300 miles an hour. For several years, it was the largest aircraft in the world. Applying change detection to the imagery allowed the U.S. to assess its capabilities and the threat it posed.

THE NRO AND MAMMOGRAPHY

In the 1990s, the medical community in the United States reached out to the National Reconnaissance Office with a critical question: Is there anything you are doing with space imagery that could improve mammography? Mr. Frank Calvelli, who went on to serve as the NRO's Principal Deputy Director, provided a presentation at a 1994 conference on new frontiers in breast cancer imagery and early detection. In his briefing, he explained that NRO technologies could improve mammography in the following areas:

- Change Detection
- Automatic Target Recognition
- Soft Copy Exploitation Systems
- High Resolution Softcopy Displays

The same tools that helped us understand over time Mys Shmidta and the Caspian Sea monster could be shared with the medical community. The sharing of this toolbox improved the quality of mammography and, as a consequence, has helped in the fight against breast cancer.

COMMUNICATIONS


Teletype Machine


Fax Machine


STU-II Secure Phone

In 1961, the NRO was formed as one of the most secret and compartmented programs in the entire U.S. Government. But how does an organization that requires a verified need-to-know before you even learn its name communicate between offices located across the country using 1960s' technology? It required a small, highly capable, innovative cabal of communicators with the money and priority to create evolutionary breakthroughs, while hiding in the shadows, even from people who thought they were cleared for the nation's highest secrets.

SMALL TEAM, BIG JOB

When the NRO was created, it consisted of personnel in three different states and Washington, D.C., and with personnel at several different locations within those states. The job of getting all those personnel to work together for a common mission was the responsibility of the NRO Director and the NRO Staff, located in an unmarked suite (Room 4C-1000) in the Pentagon. The 44-person NRO Staff had a squad-sized communications team whose responsibility was to ensure that all the various programs and detachments could communicate with each other, regardless if they worked on another floor or in a different state.

The line organization began as a 12-person detachment commanded by an Air Force captain but eventually evolved into Squadrons, Groups, and finally into a single Air Force Communications Wing of over 1,000 military and contractor personnel, with a substantial operating budget. It developed and fielded leading edge advances in secure voice and message handling, facsimile capabilities, and secure tactical dissemination systems. It also enabled the NRO to be the earliest national security adopter of commercial long-line services and at the forefront in the secure application of new digital applications, internet services, and email. Many of these NRO-led capabilities were subsequently adopted by the DoD and other government organizations, such as the White House Communications Agency, the State Department, and other government agencies.

WHAT'S A FAX MACHINE?

The initial 4C-1000 communications team of 12 Air Force communicators operated a special communications center, providing classified and unclassified communications services. Initially, the NRO relied on messages sent by teletype from communications center to communications center. "Comm centers" were established at Byeman facilities. The key component of the NRO Communications infrastructure during this period was the Special Operations Communications network or SOCOM. It was based on the standard Air Force hard-copy messaging system but with unique security keying for the NRO. Secure voice communications were serviced by the DoD's Automatic Secure Voice Communications network (AUTOSEVOCOM). Facsimile was connected through the secure voice line to provide very low-rate but secure support, particularly for small facilities not serviced by SOCOM.

In the mid- to late 1970s, NRO communicators worked closely with NSA to help fund and expedite the development of advanced technology devices, such as the Secure Telephone Unit (STU)-I and STU-II. They also contracted for development of new lightweight fax machines to operate with the STU devices to provide improved capability. The combination of secure voice and secure facsimile provided essential communications capability to smaller contractors and NRO outposts, as well as the ability to establish temporary operating sites.

One of the major accomplishments during this period was the development and stand-up of the Defense Dissemination System (DDS), which enabled near real-time imagery to flow to operational users worldwide. A new dedicated squadron that was established to support this effort included operational testing, as well as 24-hour-a-day operations.

MOVING TO THE FUTURE

The 1980s was the beginning of a revolution in communications, and the NRO was at the forefront in adopting new technologies. NRO communicators were early adopters of new high-speed long lines and satellite links that were becoming commercially available. They pioneered the development and installation of a high speed, totally integrated digital switch. This was the first operational CONUS-wide digital switch within the government that integrated both secure voice and computer data traffic, and it served thousands of subscribers.

They adapted the secure red phone system, then in use by the NRO and based initially on STU-II and then STU-III technology, to the much higher bandwidths enabled by the broadband lines and digital switches to provide a greatly improved secure voice and facsimile capability for the NRO.

By the mid-1980s, the requirement for NRO secure tactical communications had grown to the point that field users wanted more and quicker data services. The NRO communications team developed and fielded a highly portable, lightweight satellite terminal that would operate on the Defense Satellite Communications System (DSCS). This was a huge success and was adopted for use by the White House Communications Agency and also, in different variants, by the Services, the Unified and Specified commands, and the commercial communication satellites used by news organizations.

The NRO started beta testing secure email in the mid-1980s. At first, it was hosted as an application on the SOCOM computers, so it was limited to sites that hosted a SOCOM relay. Users accessed their email account via remote computer terminals hard-wired to SOCOM computers. As the commercial markets grew, the email applications were ported to desktop computers by 1990.

Today, the Communications Systems Directorate (COMM) provides end-to-end secure IT and transport services throughout the NRO enterprise and to foreign mission partners. Using state-of-the-art technology to provide satellite communications and internal cyber capabilities, COMM works with all NRO directorates and across all missions to protect and advance the strategic advantage that overhead reconnaissance provides for the security of our nation and allies.

LIGHT WEIGHT FILM

When the CIA began developing the U-2 reconnaissance aircraft in the mid-1950s, it needed a supplier of aircraft film that could meet its needs while keeping the whole process secret. So in 1955, the CIA approached Dr. Albert Chapman, president of the nation's leading film producer, the Eastman Kodak Company. Realizing the importance of the request and foreseeing a lucrative potential relationship, Chapman quickly persuaded the Kodak board of directors to agree to work with the Agency, beginning a more than 40-year relationship that would outlast the Cold War.

Aerial reconnaissance is almost as old as the airplane itself. Yet in the 1950s, the technology was not very advanced, up until then, most requirements were simply to identify large objects (industries, bombing targets, armies on the move, etc.) But the mission of the U-2 was much different, and the limitations imposed on the aircraft's sensors were much more stringent. Kodak would have to come up with revolutionary new ideas to provide the needed film for the U-2's cameras.

By the U-2's first operational flight in June 1960, the company had developed the revolutionary Kodak Special Plus X Aerial Aerographic film on .0052-inch (5.2 mil) acetate base. This film was significantly lighter than most aerial films at that time and helped Lockheed save the weight necessary to reach their target altitude of 70,000+ feet.

THE MOVE TO SPACE

When planning was initiated for the move to space with the first photoreconnaissance satellite, Corona, the government again turned to Kodak. During testing, it became apparent that the production process used for the Kodak aerial film was incompatible with a space environment, and the acetate base lost structural integrity. Aware of a new material invented by DuPont called polyethylene terephthalate (PET), or Mylar, Kodak purchased a licensing agreement from DuPont to permit Kodak to manufacture the PET with the provision that Kodak limit its use to films in photographic applications. Kodak called its new film base "ESTAR."

The ESTAR base was both compatible with a space environment as well as being significantly thinner than their previous acetate base. Measuring just .004 inches (4 mils)-thick, the ESTAR base allowed Kodak to produce smaller and lighter rolls of film to meet the strict size/weight limitations needed for space flight. The world's first photoreconnaissance satellite, Discoverer (Corona) XIV, flew on 18 August 1960, and carried a film load limited to ten pounds of 70mm-wide SO-102 film (approximately 3000 feet).

While they originally produced ESTAR base with a thickness of just 4 mils, there was the potential for producing even thinner film bases. As manufacturing techniques improved, it became possible to reduce the ESTAR base thickness to .0025 inches (2.5 mils), identified as ESTAR Thin Base film. Because the thinner base permitted a larger film payload for the same weight, all Corona flights after 1962 used this ESTAR Thin Base film.

By the late 1960s when Gambit was launching and Hexagon was under development, technological improvements allowed Kodak to produce even thinner films, the .0015-inch (1.5 mil) ESTAR, known as ESTAR Ultra-Thin Base (UTB) and the 1.2 mil ESTAR, known as ESTAR Ultra-Ultra-Thin Base (UUTB). Both of these film types flew on both Gambit and Hexagon flights. By the end of the Hexagon program, fully loaded Hexagon satellites were launched carrying 320,000 feet of film, more than 100 times the film load of that first Corona satellite, just 25 years earlier.

THE WORKFORCE

In the early days of the U-2 program, the core production operation in Kodak's Bridgehead program was comprised of approximately 50 highly trained operators, technicians, and engineers. In the 1960s, as the Corona program came on-line and the scope of production support became better defined, staffing grew to 100-130 personnel. By 1975, the total complement of all Bridgehead operations and support reached its highest level of 535 personnel. Despite all of that, there were no known security breaches about Kodak involvement in the U.S. film return satellite infrastructure throughout the program, and Kodak's involvement did not become public knowledge until the Corona program was declassified in 1995.

Kodak Black & White Film Types Used in the Corona Program

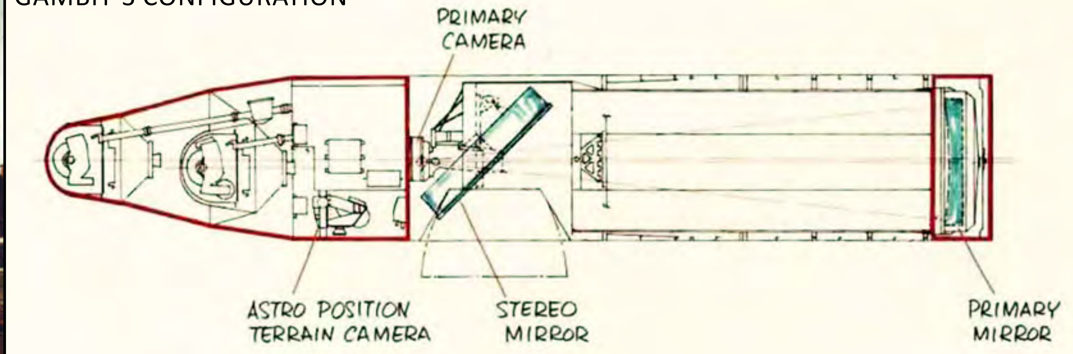
This chart identifies the film types carried as the principal film load in the various KH systems. On occasion shorter lengths of color films or B&W infra-red films were spliced into the film roll for evaluation and/or as an aid in image exploitation.

DESIGNATION	KH-1	KH-2	KH-3	KH-4	KH-4A	KH-4B
TIME PERIOD	'59-'60	'60-'61	'59-'62	'62-63	'63-69	67-72
CAMERA MFGR.	FCIC*	FCIC*	Itek**	Itek**	Itek**	Itek**
CAMERA DESIGNATION	C	C'	C'''	?	J	J-3
LENS	f/5	f/5	f/3.5	f/3.5	f/3.5	f/3.5
MODE	Mono	Mono	Mono	Stereo	Stereo	Stereo
RV	1	1	1	1	2	2
FILM WIDTH	70mm	70mm	70mm	70mm	70mm	70mm
BASE TYPE	Acetate	Acetate	Acetate/Estar	Estar	Estar	Estar
BASE THICKNESS	5.2 mil	5.2 mil	5.2mil/2 ½ mil	2 ½ mil	2 ½ mil	2 ½ mil
FILM CODE	SO-1153	SO-1153	SO-132	SO-132	3414	3414

* Fairchild Camera and Instrument Corporation
**Itek Corporation

LIGHT WEIGHT OPTICS

Kodak Facility



In mid-1963, about the time of the first Gambit satellite launch, the need for even higher photo resolution than that provided by the country's first high-resolution reconnaissance satellite was emerging. Intelligence analysts and engineers began to envision the benefits of better resolution than even the new Gambit systems could provide. However, engineering considerations with the original Gambit satellites hampered some basic areas for improvement. From a photographic payload point of view, the original Gambit configuration was non-optimal in a number of ways: redundant structural elements, thermal management subsystems, and power-distribution gear consumed more than their fair share of space and weight. These duplicated systems were crowding out possible growth elements such as larger optics, more film, and other life-extending expendables. The new Gambit-3 (aka Gambit-cubed) system was born out of these considerations. In terms of optics, those proposed for Gambit-3 were to be larger and lighter than any previously built for space use. The primary mirror was 44 inches in diameter, and the stereo mirror was a 58-inch by 46-inch ellipse. These optics were larger than those of many terrestrial telescopes, but they were required to be much lighter in weight, with optical figure accuracy at least as demanding.

BLANK MIRROR ASSEMBLY

The initial step in the production of light weight optics was to assemble the primary and stereo mirrors as "blanks" (unground and unpolished mirrors) with their support structure. The blanks were manufactured by the Corning Glass Company for Eastman Kodak. Using large boules of very pure fused (amorphous) silica glass, face and back plates were cut, as were the interior pieces, which were thin, notched, quasi-rectangular plates joined in an "egg-crate" fashion. The mirrors were assembled with the back plate supporting the egg-crate section, surrounded by side plates, with the to-be-finished face plate on top. This assembly was then placed in a large furnace where it was heated just to the melting point of silica, at which point the various pieces were fused to each other. The fusion operation was delicate: heating for too long or at too high a temperature would make the intended structure a partially molten blob, while too low a temperature or too short a time would prevent the parts from fusing sufficiently to provide structural integrity. After the fusion step, various tests were conducted to determine the percent of intended fusion that had actually taken place and to establish the geometry of any voids. After some early failures, these large, lightweight blanks were successfully manufactured by Corning and shipped to Eastman Kodak for figuring and polishing.

MIRROR POLISHING

To perform the polishing work, Eastman Kodak prepared a special facility where new, large grinding and polishing machines were built. Well-proven techniques were used, and success was largely a question of scale, as well as proper concern for the fact that the structure being ground and polished was more delicate than the usual piece of solid glass. An integral part of the figuring and polishing step was the need for repeated testing to ensure achievement of the desired optical figure. The optical figure-error budget required that the spherical primary and flat stereo mirrors be accurate to a root-mean-square value of one-thirtieth of the wavelength of light, as well as a peak-to-peak value of the same magnitude. The grinding and polishing process was initially fraught with difficulties, chief of which was the excessive time that it took to complete each mirror to get to the desired accuracy. Eastman Kodak originally estimated that each mirror would require about 800 hours of grinding, polishing, testing, and coating from the raw blank to the finished product. However, the process ran as high as 3,000 hours per mirror and initially put the system behind schedule. Eventually, Eastman Kodak was able to reduce the production time, and the program was back on track. By 1964, Eastman Kodak had progressed to where it had developed sound techniques for manufacturing the large, but lightweight optics. The first Gambit-3 launched in 1966 and provided image resolution about twice as good as the original Gambit systems.

PROCESSING OF LARGE DATASETS

Kodak - Bridgehead

IDEX

MISSION IMPERATIVE

The NRO has been on the cutting edge of processing data and finding new solutions to handle large capacity datasets since its inception in the early 1960s. From recording telemetry data onto magnetic tapes, to processing of film returned from space, to today's processing of near real-time data, a massive amount of data pours into the NRO every day. The structuring and dissemination of large datasets is critical. To meet this challenge, the NRO utilizes integrated architecture that brings together data from all sensors in ways that refine products, streamline delivery, and create more value-added content for policymakers, analysts, warfighters, and other mission partners.

EARLY DATA ACQUISITION

Processing large datasets originated from data acquisition of early electronic intelligence search and technical collection satellites GRAB and Poppy. These Elint satellites targeted the Soviet Union's air defenses using radar pulse signals in specified bandwidths, and they transmitted corresponding signals to radio receiving and control ground huts within their fields of view. Cryptologic elements of the Army, Navy, and Air Force then coded, converted, and recorded this radio telemetry data onto magnetic tapes. Couriers carried magnetic tape recordings back to the Naval Research Laboratory, where technicians evaluated, duplicated, and forwarded the data to National Security Agency and the Air Force Strategic Air Command for analysis and further processing.

Advances in Elint satellite technology increased the volume and density of radar intercept data, overwhelming then-existing analytical capabilities. This stimulated development of computer-aided approaches at the NSA, NRL, and SAC. Such innovations led to increased volume, accuracy, and timeliness of reports on weapons systems. Intelligence collected from early Elint satellites supported a wide range of intelligence applications, helping the U.S. win the Cold War and laying the foundation for future Sigint and Geoint reconnaissance capabilities.

EXPLOITATION AND DISSEMINATION

NRO launched a series of successful film-recovery photoreconnaissance satellites—Corona, Gambit, and Hexagon—in the 1960s and 70s. Corona alone collected more than 860,000 images of the Earth's surface between 1960 and 1972, and Gambit and Hexagon were even more prolific. These satellite systems acquired photographs with telescopic camera systems and loaded the exposed film into recovery capsules. The exposed film was delivered to Kodak/Bridgehead for image processing and on to photo-interpretation analysts for evaluation. NRO partnered with Kodak/Bridgehead to manage the high volume of imagery collected, which led to innovations in improved black and white film processing techniques and advances in duplicating the original film negatives for exploitation and analysis. These images were used for reconnaissance and to produce maps for U.S. intelligence agencies. The success of these satellite programs created an appetite and dependency on satellite photoreconnaissance and led to a desire for increased volume and quality, as well as decreased time to receive imagery. In the film return era, it could take up to several weeks between target acquisition and exploitation of the imagery by the Intelligence Community.

ADVANCES IN SATELLITE TECHNOLOGY INCREASE DATA COLLECTION AND PROCESSING

Enter Kennen, the world's first high-resolution electro-optical satellite. Launched in 1976, Kennen made imagery available to analysts so quickly the process is called "near real-time." Unlike film-return systems, Kennen electronically down-linked its imagery in near real-time, providing a relatively steady stream of digital imagery to analysts after collection and processing. The NRO created from whole cloth new processes and infrastructure to process this new type of imagery.

As NRO's satellites became more sophisticated, the data stream grew in velocity, volume, and variety, and it overwhelmed established capabilities to process and disseminate information. Data acquisition became more critical, and the equipment needed to evolve to perform advance manipulation of this data. New techniques were developed to turn digital data into imagery for exploitation in support of intelligence analysis. The imagery needed to be processed, searched, retrieved, disseminated, and achieved in ways that had not been possible before. This required moving beyond the use of more traditional light tables to new technology.

During this same period, supercomputing capabilities were emerging in the United States. New computing technology provided greater efficacy in running complex simulations and mining unrelated large datasets allowing for more analysis and less searching. The NRO was able to leverage cutting edge computing technologies to meet the challenge of maximizing the exponential growth in imagery data collection from the Kennen program.

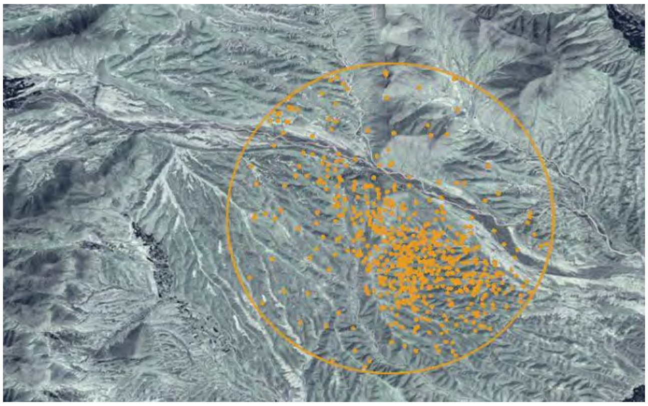
LAYING THE FOUNDATION FOR DATA SCIENCE

Advancements in space reconnaissance programs presented numerous challenges to processing large datasets for faster transmission of timely intelligence to policymakers, intelligence consumers, and warfighters. Solutions were needed. In 2008, the NRO established the Ground Enterprise Directorate (GED) as an infrastructure to deliver big data automation, speed, machine learning, and advanced sense-making necessary to optimize the value of overhead intelligence. Through micro-second timing, near real-time relays and processing, raw data is converted by individual sensors and receivers into millions of usable intelligence products on a global basis every day. It is now routinely feasible for analysts and managers throughout the Intelligence and user Community to obtain, on demand, positive intelligence in response to immediate needs. Through such accomplishments, NRO helped to lay the foundation of what today is called "data science."

SUPPORT TO WARFIGHTERS

The speed at which the warfighter is able to collect, process, analyze, and understand data directly impacts mission success. By the 1980s, NRO's improved technology applied in space and on Earth opened the way to using near real-time overhead intelligence for tactical support of military forces. With an expanding arsenal of sensing capabilities, multi-intelligence fusion methods, and a commitment to collaboration across communities, NRO systems and secure networks have ensured the timely delivery of accurate, insightful, life-saving intelligence (including real-time identification, detection, localization, and tracking of contacts of interest) to combat commands.

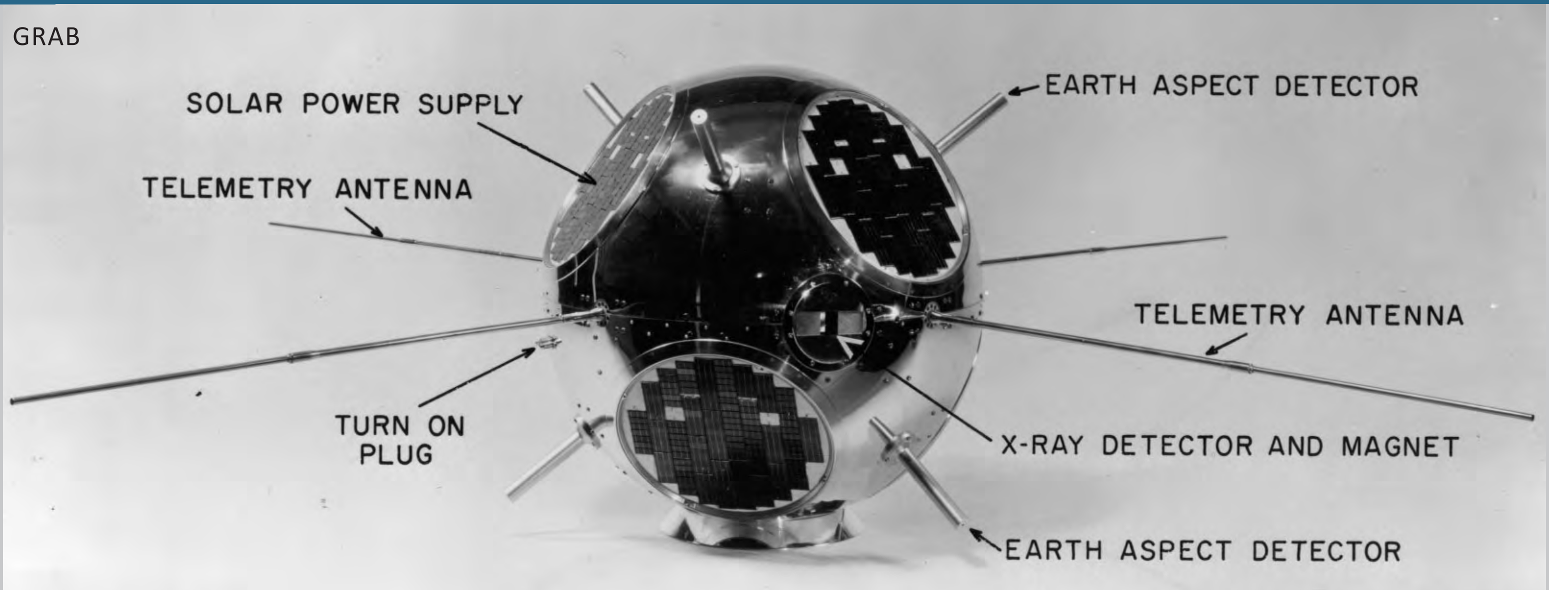
One example is the use of displayed visualization of large volumes of multi-source data to detect changes that reflect patterns of human activity. These geospatial patterns, when temporally displayed, are not only valuable for military mission planning, but also for battlefield forensics. When the geospatial display, which can render millions of data elements, is given temporal motion (i.e., reflect the changes over time), trends emerge that suggest specific activities, such as communications patterns, that can explain battlefield activities.



Millions of data elements from multi-intelligence Sources as temporally and geospatially displayed on an overhead Image. (Source: Unidentified overhead image; courtesy of CSNR Reference Collection.)

SOLAR CELL TECHNOLOGY

GRAB



THE SPACE RACE

After the October 1957 launch of the Soviet Union's Sputnik satellite—its only purpose was to emit radio pulses to make its presence known to the world—the United States' focus intensified on launching a satellite into space. In January 1958, the U.S. successfully launched the Explorer satellite. The satellite's payload carried a cosmic ray detection sensor to assess the radiation environment around the Earth, leading to confirmation of the Van Allen radiation belt theory. Both the Sputnik 1 and Explorer 1 satellites were powered by batteries. Sputnik operated for three weeks before its batteries discharged. The more elegantly designed Explorer satellite transmitted scientific data for nearly four months until its batteries discharged.

POWER FOR LONGER MISSIONS

The United States recognized that a sustainable power source was necessary to carry out longer satellite missions—one option being development of better batteries and the other incorporation of solar cells to power satellites. The U.S., and the NRO in particular, invested in both technologies to prolong on-orbit operations.

The Naval Research Laboratory, out of which one of the NRO's signals collection satellite programs would emerge, was the first organization to incorporate solar cells to power a satellite. NRL's Vanguard satellite, launched in March 1958, was designed to assess radiation effects on space vehicles and also use radio signals to provide geodesic information on the Earth. The satellite carried mercury batteries to power the satellite, but was also the first satellite to incorporate solar cells as a power source. The success of solar cells on the Vanguard I satellite prompted their use on other satellite vehicles.

FIRST SOLAR-POWERED RECONNAISSANCE SATELLITE

In addition to developing the Vanguard satellites, the NRL undertook a classified signals collection satellite development program in the same timeframe. The project was called the Galactic Radiation and Background satellite or GRAB. To cover the true nature of the satellite, NRL indicated it would carry experimental sensors to better understand radiation in space. GRAB's true purpose was to capture Soviet radar returns to better understand their air defenses. GRAB became the nation's first successful operational reconnaissance satellite when it launched in June 1960.

Drawing on NRL's early expertise in solar cell use in powering satellites, engineers designed GRAB to be powered by both batteries and solar cells. With the establishment of the NRO in 1961, the Kennedy administration included NRL's signals collection satellite program in the new organization. As part of the NRO's Program C, NRL engineers developed a follow-on satellite to GRAB named Poppy. Like the Vanguard and GRAB satellites, Program C satellite developers designed the satellites to include solar cells for power. In a very innovative approach to using solar cells on a satellite, Program C engineers designed later Poppy satellites to be covered with solar cells on almost all of their exteriors. This later generation vehicle was known as the Multi-Faced Poppy satellite.

EVOLUTION OF POWER FOR IMAGERY SATELLITES

By the 1960s, solar cells became a power source for most earth orbiting satellites and probes launched to better understand the solar system. The NRO's early imagery satellites were powered by the Agena control vehicle carrying battery cells, later supplemented by solar cells. The Agena vehicle was originally designed as a boost vehicle for placing satellites into proper orbits. As used by the NRO, it not only served that purpose, but also served as an orbital control and support vehicle for the imagery optical payloads for both the Corona and Gambit systems.

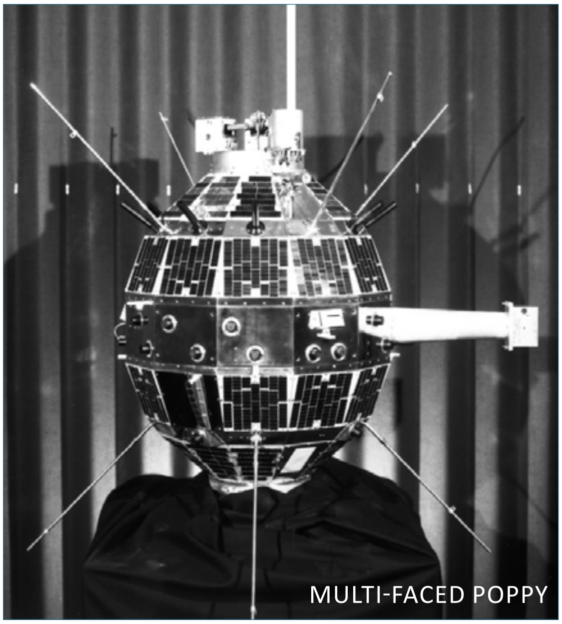
One of the significant limitations of both the Corona and Gambit systems was that they carried film supplies, and in early versions, only a single film return capsule. As a result, the missions ranged from a few days to a few weeks, at most, before the film was exposed and returned to Earth for processing and exploitation. Since the early Corona missions were short, battery power proved adequate for supporting early imagery collection satellites. With the development of dual return vehicles first on Corona and later on Gambit, the NRO's satellites required a battery and solar-cell-powered Agena.

The NRO's CIA component, Program B, undertook an ambitious program in the mid-1960s to develop a large imagery satellite that could obtain imagery for several months. The program was named Hexagon, a satellite the size of a locomotive, carrying 60 miles of film, and four film-return capsules. To power the satellite and recharge its batteries, the Hexagon vehicle included two large solar arrays on the aft of the vehicle. The arrays incorporated state-of-the-art solar cells and provided the necessary power for the large satellite and its much longer mission life compared to the earlier photoreconnaissance satellites launched by the NRO.

SOLAR CELL DEVELOPMENT CONTINUES

In 1976, the NRO launched the first Kennen imagery satellite, designed to obtain electro-optical images in near real-time. This advancement not only allowed for much longer mission operations for imagery satellites but also required sustainable power from solar cells while on orbit. As with developments in imagery collection capability, the NRO developed more advanced signals collection satellites that also required improved power sources. The NRO continued to invest in solar cell development to enable advances in satellite vehicles and their improved capabilities.

In particular, the NRO pushed gallium arsenide (GaAs) solar cell development with multi-junctions and exotic layering of materials. These cells are now used extensively on commercial spacecraft. However, GaAs solar cells were more expensive to manufacture and are known to be more brittle than traditional silicon materials, and thus the panel materials when constructed have to be appropriately heavier – a downside in launching satellites. The NRO supported development of high-efficiency silicon solar cells resulting in efficiency improvements that reached 17% efficiency. Solar cell designs of these types are also prevalent now in the industry. Additionally the NRO supported development of indium phosphide (InP) solar cells, achieving 18% efficiency and more radiation hardening than with GaAs solar cells.



MULTI-FACED POPPY

CENTER FOR THE STUDY OF
NATIONAL RECONNAISSANCE

MAY 2023