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Analytical Article

Looking Closer and Looking Broader: Gambit and Hexagon — The Peak of Film-Return Space Reconnaissance After Corona*

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Looking Closer and Looking Broader: *Gambit and Hexagon–The Peak of Film-Return Space Reconnaissance After Corona*

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In his 1986 State of the Union Address, President Ronald Reagan remarked,

> *". . . the threat from Soviet forces, conventional and strategic, from the Soviet drive for domination, from the increase in espionage and state terror remains great. This is reality. Closing our eyes will not make reality disappear."*

Like his five predecessors dating back to the early 1960s, President Reagan had eyes on the Soviet Union and saw the reality of its strategic threat. Those eyes were the National Reconnaissance Office's (NRO's) imaging reconnaissance satellites: first, Corona from 1960 to 1972, and then joined and subsequently replaced by the peak of film-return space reconnaissance systems—the Gambit surveillance system that, from July 1963 through August 1984, used its high resolution to look closer at intelligence targets; and the Hexagon wide-area search system that, from June 1971 to October 1984, used its ground coverage capabilities to look broader across the Earth's surface.

The technical details of these two systems describe an amazing set of capabilities, especially considering that engineers pioneering satellite technology in the period made their calculations with paper and pencil and slide rules, programmed satellite commands on punch cards, and communicated with typewriters. The first part of this article summarizes those details. The second part summarizes the systems' intelligence contributions to national security—contributions that proved to be invaluable to a series of U.S. Presidents.

Gambit and Hexagon gave the Presidents enough confidence in their knowledge of the strategic threat to national security that they were willing to enter into arms control agreements with America's Cold War adversary, the Soviet Union. After two and a half years of Strategic Arms Limitations Talks (SALT) with the Soviets, on 26 May 1972 U.S. President Richard Nixon signed the Anti-Ballistic Missile (ABM) Treaty and the Interim Agreement on strategic offensive arms with Soviet General Secretary Leonid Brezhnev in a ceremony in Moscow. The Nixon administration was confident that the Gambit and Hexagon-acquired intelligence would provide an objective, reliable means of verification and enforcement. Both arms control documents used the phrase ". . . each Party shall use national technical means of verification at its disposal" (U.S. Department of State, 1972). The phrase "national technical means," or "NTM," meant satellite reconnaissance—a capability that was so sensitive and highly classified at the time that the U.S. was unwilling to publicly acknowledge it. The sensitivity was a consequence of the phenomenal capabilities that these National Technical Means offered in the 1960s, 70s, and early 80s.

What were the Gambit and Hexagon "National Technical Means?"

By 1963, the revolutionary Corona photoreconnaissance satellite had been capable of acquiring images with a resolution within the 10- to 20-foot range, but the second Gambit-1 KH-7[1] mission in that same year acquired imagery with a best resolution of 2.5 feet[2]—comparable resolution to what cameras on the U-2 reconnaissance aircraft could acquire. This was a remarkable qualitative leap forward less than three years after the CIA and Air Force had launched the first successful Corona mission. By 1966, the Gambit-3 KH-8 system further improved resolution with a 160-inch effective focal length optical system, a five-foot diameter and 43 ½ inch aperture. The NRO continually improved the Gambit's resolution throughout the life of the program by upgrading the optics, satellite control, satellite vehicle stability, and film. Figure 1 shows an image of the KASPIYSK (see footnote 3) Special Research and Development Facility taken on the final KH-8 mission. Some argue that its ultimate best resolution was so good that it remains sensitive and cannot be revealed at the time of this writing.

The Hexagon system had its own sensitivity and represented another technological leap forward. Its twin panoramic cameras could photograph a 300 nautical miles (nm) wide by 16.8 nm long ground area in a single frame (more than 3 times the area acquired by

Figure 1. KH-8 (M4354) Image of the "Caspian Sea Monster" at the KASPIYSK Special Research and Development Facility.

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[1] The KH-7 designator referred to the system's camera and imagery and stood for "KeyHole," the IC's security control system for overhead satellite reconnaissance products. The number "7" refers to the 7th satellite photointelligence system (see sidebar "What's in a Name – Gambit") (McDonald, 1997).

[2] Resolutions given are in ground resolved distance (GRD), a measurement of image quality applied to film satellites that indicates the distance two objects need to be apart to be distinguished as separate from each other (McDonald, 2002).

Corona's cameras) to produce nominal 1:100,000 scale images that could be magnified up to 100 times. At its nominal operating altitude of 100 nm, and a scan angle of 120 degrees, the panoramic cameras could scan 370 nm in one frame—covering approximately the distance between Washington, D.C. and Cincinnati, Ohio. This was an astonishing capability that, for example, could allow the U.S. to monitor individual Soviet and Chinese nuclear test sites that KH-9 photographs could capture completely in a single image.[3] Figure 2 shows a KH-9 image taken over Shea Stadium in New York. Initially the Hexagon satellite operated only with panoramic cameras for collecting intelligence, and then for later missions it added a mapping camera system for collecting mapping imagery. Over Hexagon's lifespan, its mapping camera succeeded in imaging most of the Earth's land surface (excluding much of Australia, and the polar icecaps of Greenland and Antarctica).

Hexagon's broad-area coverage with superior resolution and Gambit's unusually high-quality, space-based imagery provided the U.S. Intelligence Community (IC) with

Figure 2. KH-9 (M1216) Image of Shea Stadium.

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[3] Hexagon's capabilities enabled the system to capture "fleeting events of intelligence interest" (Oder, Fitzpatrick, & Worthman, 1992, p. 203), such as its inadvertent imaging on M1213 of a Soviet vessel, the KASP-B, being pulled by tugboats to an unknown location. Mostly because of Gambit imagery, U.S. intelligence had discovered this huge vessel with indeterminate mission in 1967 and dubbed the mysterious craft the "Caspian Sea Monster" (1992).

comprehensive, high-quality photographic coverage through complementary satellite missions of area search—the ability to "look broader"—and high-resolution surveillance—the ability to "look closer." When the Hexagon KH-9 cameras detected a new target of interest on the search mission, the NRO would precisely point Gambit KH-8 cameras at the area or object on the surveillance mission to give a high level of detail. Both systems returned images that photo interpreters could magnify 100 times their original size. These state-of-the-art—and therefore highly sensitive at the time—film-return satellite reconnaissance systems had a major impact on the national security policymaking and operations of six American Presidents throughout the Cold War. Along with parallel and successor systems, Gambit and Hexagon played a significant role in reducing military and diplomatic tensions between the two global superpowers of the U.S. and U.S.S.R. They were the "National Technical Means" that were too sensitive to identify.

The Gambit and Hexagon programs built upon Corona's legacy. Both Gambit and Hexagon acquired images on film that they stored in on-board "buckets" and subsequently returned to Earth in heat-shielded recovery vehicles (RV). The programs used C-119 and C-130 aircraft recovery systems comparable to what engineers had pioneered for Corona (see Figure 3, "Aerial Recovery of Hexagon Film by JC-130 Aircraft"). Although their data retrieval method was showing its age by the first Hexagon launch in 1971, and the NRO had begun system definition for a more time-responsive digital system, both Gambit's and Hexagon's imaging capabilities represented breathtaking advances over Corona.

Figure 3. Aerial Recovery of Hexagon Film by JC-130 Aircraft
(Reprinted from Oder, et. al., 1992, p. 98).

Looking Closer to Assess the Adversary's Capability—How Did Gambit Do it?

Gambit's high resolution camera system provided the U.S. its first ever close-in satellite surveillance capabilities,[4] which enabled analysts to assess the adversary's scientific and technical capabilities. The NRO developed and flew two versions of the Gambit satellite, the Gambit-1 with the KH-7 camera, and its successor, the Gambit-3 ("cubed") with the KH-8 camera. Gambit-1 was one of the first satellite programs developed under the auspices of the Office of the Secretary of the Air Force for Special Projects (SAFSP)—what would become the NRO's Program Office A—and using National Reconnaissance Program budget dollars. The NRO operated Gambit-1 from July 1963 to June 1967, numbering the KH-7 missions with a 4000 series, 4001 to 4038, and Gambit-3 from July 1966 to August 1984, numbering the KH-8 missions 4301 to 4354 (see Table 1) (Oder, Fitzpatrick, & Worthman, 1991).

What's in A Name—Gambit

U.S. Air Force Colonel Paul J. Heran is generally credited with naming Project Gambit, a codename that evoked the tactics of a chess move. The program office and others used additional names for the Gambit project.

To conceal the existence of Gambit-1's highly-sensitive development at its program initiation, the Director of SAFSP, Brig Gen Robert E. Greer invented a "null" program—one having no origin or acknowledged goal. The program office used this "null" program name—Program 307—to purchase the hardware under the Air Force's Space System Division (SSD), without reconnaissance association. The NRO further obscured Gambit procurement activities within "Project Exemplar," a classified activity for which the goal was four space launches beginning in February 1963 from the Pacific Missile Range. The unclassified codename for Project Exemplar was "Cue Ball." Gambit-1 also had an overt Air Force identifier of "Project 206."

There was no Gambit-2. After conducting studies for an "advanced Gambit" system, Eastman Kodak presented the NRO with three options for the optical system, called respectively Gambit-2, Gambit-3, and Gambit-4, in ascending order of resolution improvement and cost. The NRO chose Gambit-3 as the optimal compromise of required resolution improvement and acceptable cost and development schedule. The Gambit-3 was often referred to as "Gambit Cubed." In program management planning documents, Gambit-3 carried the overt Air Force identifier of "Project 206-II," which later changed to "Project 110."

The user community in the "Talent-Keyhole" world knew of these systems as the "KH-7" for Gambit-1 and "KH-8" for Gambit-3 (McDonald, 1997; Classified source, CSNR collection).

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[4] Gambit was not, however, the first high-resolution imagery satellite that the NRO produced; on 18 March 1963, the NRO launched a high-resolution imaging satellite called Lanyard, which featured a 66-inch focal length, f/6.0 optics camera—designated the KH-6—that the Itek Corporation had manufactured for the Samos program. The Lanyard satellite failed to reach orbit on that first mission because of an Agena-B upperstage malfunction. The NRO would produce five Lanyard satellites, three of which launched, but only one returned any imagery. The Lanyard system had been deemed necessary when U.S. Secretary of Defense Robert McNamara became concerned about intelligence reports of suspected Soviet anti-ballistic missile development. When McNamara requested high-resolution imagery of a suspected site in early 1962, DCI John McCone urged DNRO Joseph Charyk to expedite launching the first Gambit satellite. Charyk's awareness of the program's progress convinced him that the first Gambit launch would likely happen no earlier than mid-1963, and he consequently signed an agreement to have the Air Force and CIA jointly produce the interim Lanyard satellite (Oder, et. al., 1991; McDonald, 1997; Classified source, CSNR reference collection).

The Gambit-1. The Gambit-1 KH-7 camera system collected satellite imagery with reconnaissance aircraft imagery quality—and nearly 50 years before commercial satellite imaging systems and "Google Image" were regularly making high-quality space imagery available to the public. Gambit proved the viability of high-resolution space photography. On 6 September 1963, the date of the NRO's second anniversary, the second Gambit-1 satellite—the first mission was little more than a one-day trial flight[5]—launched from Vandenberg Air Force Base on an Atlas launch vehicle (LV) with Agena-D upperstage[6] that thrust the satellite into a near-polar orbit, some 110 nm above the Earth's surface. The KH-7's camera completed the two-plus days of its photographic mission, and after a C-119 aircraft caught the returning film capsule and analysts exploited the film, the Intelligence Community (IC) discovered 1,930 feet of exposed film containing imagery that included 10 priority intelligence targets, with a best resolution of 2.5 feet, as already noted. That resolution was unprecedented for a satellite system and the demonstrated capability held tremendous potential intelligence value because the detail revealed in higher-resolution imagery enabled IC photo interpreters to do scientific and technical analysis of Soviet and Chinese weapon systems, a type of analysis that had not been possible with earlier satellite imaging systems (Oder, Fitzpatrick, & Worthman, 1991; Smith, 2002).

How did Gambit achieve such high-resolution photography? The camera's lens produced a larger image at the focal plane, providing substantial resolution improvement. The KH-7 featured a Matsukov-type strip camera[7] with an aperture of 19.5 inches, an effective aperture of f/4.0, and an effective focal length of 77 inches. The KH-7's photo resolution of 85 lines/mm translated to a ground resolution at nadir of about 2 feet. This resolution was considered very good in 1961 when the Gambit development was initiated and was still comparable to some of the best available commercial systems launched in the late 1990s and early 21st century (e.g., Quickbird and IKONOS).[8]

Of course, increasing focal length was not the only means to improve resolution: although Corona's designed 24-inch focal length camera never got any larger on the later KH-4 cameras, the NRO consistently improved its resolution by changing the thermal design, upgrading the quality of manufacturing and testing, understanding and adjusting

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[5] The first KH-7 mission returned just 198 feet of film, with only 3 intelligence targets imaged among its 74 exposed frames (NRO, 1991).

[6] The Lockheed Missiles and Space Company introduced the Agena-D in 1962, which standardized interfaces, improved component accessibility, and integrated the guidance and power systems of the spacecraft. Both KH-7 and KH-8 Gambits used the Agena-D (Standard Agena) over the life of the program (Powell, 1997).

[7] Dmitri Maksutov (b. 1896) was a Russian-born pioneer in the field of optical telescopes. In 1941, he produced the meniscus telescope. In the late 1940s and 1950s, Maksutov oversaw fabrication of many large-aperture optical systems. A strip camera "continuously exposes a narrow strip on the film as the camera passes over the area being photographed" (NRO, 1963, p. 7). The KH-7 strip camera system photographed small target ground areas through a narrow slit near the camera focal plane and could produce stereo pairs, lateral pairs, and strip photography up to a maximum of 600 stereo pairs or an equivalent amount of continuous strip photography per mission.

[8] It should be noted that commercial satellites' resolution is controlled by the U.S. Government. As of 2011, commercial remote sensing licensing granted by the National Oceanic and Atmospheric Administration (NOAA) limits commercial imagery's resolution to no better than 0.5 meter (1.64 ft.) ground sampled distance (GSD) for black and white imagery, and 2.0 meters (6.56 ft.) GSD for multispectral imagery.

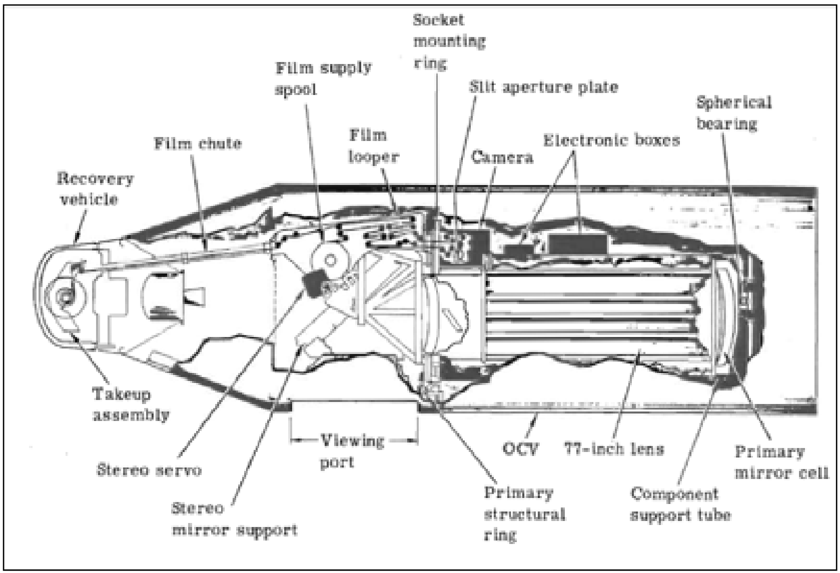

Figure 4. Gambit-1/KH-7 System Diagram
(Reprinted from classified source,CSNR reference collection).

for orbital temperature effects on focus, and improving orbital vehicle stability, film, and film processing (NRO, 1982). Gambit operators used yet another method to get sharper pictures, which was to fly in very low orbiting altitudes of approximately 80–90 nm above the earth (the NRO could fly Corona's KH-4B system as low as 80 nm, too), requiring command system orbital adjustments to keep the satellite from an uncontrolled re-entry into Earth's atmosphere. On one later KH-8 mission, the NRO flew the satellite as low as 63 nm (NRO, 1963; Oder, Fitzpatrick, & Worthman, 1991; NIMA, 2002; Smith, 1997).

The NRO attempted 38 Gambit-1 surveillance satellite missions from July 1963 to June 1967. Ultimately the Gambit-1 program was a success, with 36 payloads reaching low earth orbit and 34 being recovered, but the early flight program experienced a myriad of challenges. A significant number of the first 23 missions were plagued with flight issues caused most frequently by control gas valves in the orbital control vehicle (OCV), and the intelligence value of returned film was minimal in a majority of the first 14 missions through 1964. Once the NRO corrected the valve and other problems, Gambit-1 had very good operational success, with 15 of the final 17 missions returning imagery of more than 1,000 intelligence targets each, at best resolutions of 2 feet GRD. Taken together, the 29 successful missions (i.e., missions providing meaningful imagery intelligence; see mission summaries in attachment) returned 19,000 frames, some 43,000 linear feet of film, and captured 27,534 intelligence targets (see Figure 4 for a KH-7 system diagram) (Oder, Fitzpatrick, & Worthman, 1991; NIMA, 2002).[9]

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[9] The average number of KH-7 targets per mission increased over time, from 4.25 in the first year to 1,824 for the three 1967 missions, the last year of KH-7 flights (Oder, Fitzpatrick, & Worthman, 1991).

Mission Duration Comparison:

Gambit-1 vs. Gambit-3

The shortest successful Gambit-3 mission—its first, Mission 4301—lasted 6 days (5 photographic days), nearly equal to the longest Gambit-1 mission (8 days). Gambit-3's mission 4353 acquired 27,652 frames of imagery, containing 49,372 targets, more than the combined photographic take of all Gambit-1 missions put together.

The Gambit-3. The Gambit KH-8 camera system provided imagery that was significantly sharper and of higher quality than Gambit-1 imagery. It used a camera with an effective focal length more than double the KH-7's camera (160 inches to 77 inches) and used higher quality film and processing techniques.[10] The final KH-8 camera had a 175-inch focal length, f/4 Newtonian prime lens with Ross corrector that gave a ground resolution so good it is still considered too sensitive to reveal. The system could be operated in a number of different modes to produce stereo (up to 2000 stereo pairs for the original KH-8 system) or monoscopic strips, and lateral pair or lateral triplet photography. Another primary reason for the KH-8's very high quality imagery was improved orbital control and payload maneuvering through the use of a modified Agena incorporating an ingenious roll joint that rotated the camera in a plane perpendicular to the line-of-flight of the satellite vehicle (see Figure 5). By contrast, Gambit-1 used a 15-foot long orbital control vehicle that expended attitude control gas to perform roll maneuvers. A counter-rotating wheel on the Gambit-3's roll joint compensated for the sweeping motion of the payload and helped maintain Earth orientation. Later versions of the roll joint were capable of thousands of operations per mission. Gambit's pictures provided photo interpreters with a level of detail they had never gotten from satellite photos before, and would not again for some years. The NRO flew the Gambit-3 system operationally for a remarkable 18 years (1966 to 1984), during which time it completed 50 successful satellite missions in 54 attempts.[11] Whereas more than half of Gambit-1 missions lasted fewer than 5 days and the longest Gambit-1 mission lasted 8 days, no successful Gambit-3 mission lasted shorter than 5 days, and the longest mission was 126 days (see "Mission Duration Comparison" box). Consequently, the KH-8 returned many more photographic frames on average per mission than the KH-7. Although it is difficult to calculate the total number of KH-8 targets (one historical estimate puts it at approximately 675,000), as a point of comparison, the penultimate mission (M4353) alone photographed 49,372 targets on 27,652 frames, more than the combined photographic take of all KH-7 missions (Oder, Fitzpatrick, and Worthman, 1991).

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[10] Eastman Kodak developed improved photographic films throughout the Gambit and Hexagon programs' lifespan. To improve both film speed and resolution, Kodak produced high-definition (Type-1414) and fine-grain (SO-217) film, and "monodispersed" films with silver-halide crystals that were uniform in size and shape (Oder, et. al., 1991).

[11] Multiple references credit 51 successful missions, using imaging operations as the primary success criteria; however, Mission 4311's imagery take never got to the users. Upon completion of 10 imaging days in January 1968, the satellite vehicle ejected the recovery vehicle as expected, but the parachute malfunctioned and the NRO failed to recover the film. The loss of the imagery qualifies as a failed intelligence mission, and so we have counted it as an overall mission failure (see Mission Table attachment) (Classified source), CSNR reference collection; Oder, Fitzpatrick, & Worthman, 1991).

One key to the Gambit-3's longevity was the NRO's willingness and ability to make continual improvements to the system, the more significant of which were called satellite block changes. Mission 4332 added the R-5 optical system with a 175-inch, f/4 Newtonian Prime lens and Ross corrector that improved performance an estimated 30 percent and set a new resolution standard on its first mission. Mission 4332 also saw the first use of the "stretched tank" Titan-IIIB (24B) (LV). Several times the NRO upgraded the critical roll joint to increase the number of maneuvers that could be made throughout a mission. This became an increasingly vital feature after the Gambit-3 program office adopted on M4323 a two-RV configuration, because the roll joint (Figure 5) also compensated for change in the satellite's mass and rotational inertia that occurred with the separation of the first RV. The two-RV Gambit system, the first block II Gambit-3, enabled longer length missions and the potential for more time-responsive exploitation.

One of the drawbacks with film-return systems was they could not provide finished intelligence data quickly enough to be communicated in the moment global crises developed—a capability the NRO would not have until it launched near-real-time, electro-optical satellites—but the two-RV Gambit system, with the capability to return the first RV on demand, allowed the NRO to monitor critical global situations without having to curtail an ongoing mission or wait until it concluded. After the first RV separated from the satellite, the remaining film was loaded into the second vehicle and the satellite resumed its mission (the same principle applied to Hexagon's four-RV configuration) (Oder, Fitzpatrick, & Worthman, 1991).

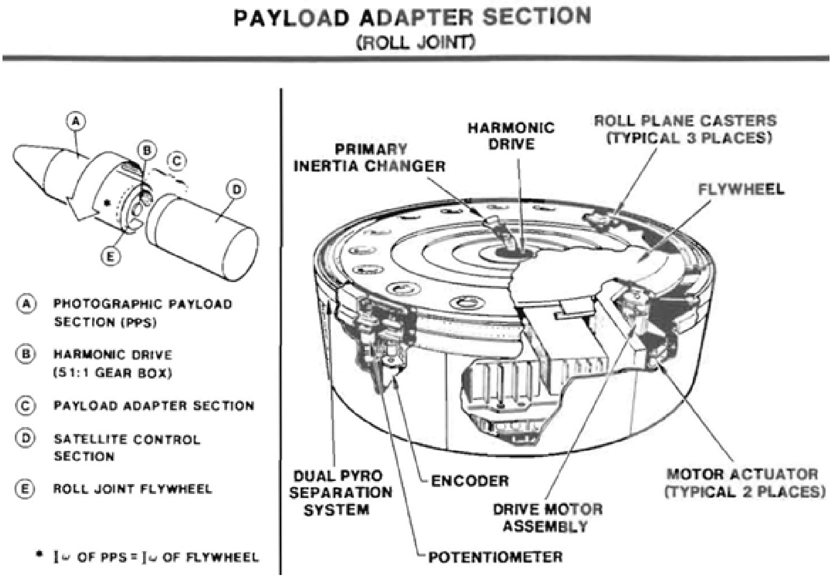

Figure 5. Gambit-3 Roll Joint (Reproduced from Oder, et. al., 1991, p. 57).

NRO Program Name, Overt ID	Gambit-1, Program 206	Gambit-3, ("cubed") Program 110	Gambit-3, ("cubed") Program 110
Camera System	KH-7	KH-8, 160-in focal length	KH-8, 175-in focal length, R-5 lens
Camera Type	Strip	Strip	Strip
Mission Numbers	4001 - 4038	4301 - 4331	4332 - 4354
Period of Operation	Jul 1963 - Jun 1967	Jul 1966 - May 1971	Aug 1971 - Aug 1984

Table 1. Gambit's Primary Cameras, Mission Numbers, and Period of Operation

Looking Broader to Find Intelligence Targets of Interest--How Did Hexagon Do it?

Hexagon's primary panoramic camera provided improved search coverage and resolution and its mapping camera provided global geodetic positioning, accurate point locations for military operations, and data for military targeting.[12] Hexagon, with its multiple recovery buckets and extended mission life, moved the U.S. closer to achieving continuous space imaging capability. In 19 successful missions (see Mission Summaries in attachment). Hexagon exhaustively photographed and accurately charted virtually all the world's inhabited regions. Using an average of 230,000 linear feet of film per mission (with 308,000 linear feet being the most film used on a single mission), and capturing cloud-free imagery of about 80 percent of its primary Sino-Soviet bloc target area, Hexagon returned a tremendous volume of usable imagery for photo-interpretation. Early requirements planning called for area coverage per mission of approximately 20 million square nm (snm), but Hexagon exceeded the coverage requirement by as much as three times on a few missions. Hexagon missions averaged nearly 130 days in length (see Mission Summaries in attachment), performing up to 2,000 imaging operations and returning up to 60,000-plus frames of panoramic imagery per mission. The NRO operated Hexagon between June 1971 and April 1986 and numbered Hexagon missions with a 1200 series, numbers 1201 to 1220.[13] It was America's last film-return national reconnaissance satellite (Oder, Fitzpatrick, & Worthman, 1992; NRO, 2011).

The first Hexagon mission, number 1201, launched 15 June 1971 at 1141 Pacific Daylight Time from Vandenberg Air Force Base in California. Recovery vehicle number one (RV-1) separated five days later, 20 June, but its parachute was damaged, and it had to be retrieved from the Pacific Ocean. Following transport to Rochester, New York, and processing by Eastman Kodak, one NPIC representative at the facility reportedly reacted with glee: "My God, we never dreamed there would be this much, this good!" (quoted in Oder, Fitzpatrick, and Worthman, 1992, p. 97). Throughout its operational lifespan, the NRO launched Hexagon from Space Launch Complex-4 East (SLC-4E) at Vandenberg,

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[12] Corona had proven the viability of space-based imaging with its first successful launch and film recovery on 18 - 19 August 1960; Hexagon succeeded Corona as the NRO's broad-area search and surveillance and mapping satellite.

[13] The last mission scheduled to commence in April 1986 never made it into orbit because the launch vehicle exploded nine seconds after liftoff.

What's in A Name—Hexagon

The Hexagon program originated as "Fulcrum," a CIA-sponsored series of studies and preliminary development activities intended to design optimal specifications for the next-generation search and surveillance satellite. After becoming DNRO on 1 October 1965, Dr. Alexander Flax renamed the program: "I always wanted to assign a name to a system, so I chose 'Helix,' but it was tossed back at me," Flax recalled. "Then I chose 'Hexagon,' which was an interesting little twist because it had to do with the rotary optical bar, suggesting that shape, and it also said the Pentagon, plus one" (Classified interview, CSNR reference collection).

At the time of its first launch in June 1971, Hexagon was the largest satellite the NRO had ever attempted to boost into orbit. The satellite vehicle measured 10 feet across and 59 feet long, and weighed about 27,000 pounds, including the shroud and booster adapter. Hexagon's unprecedented size prompted a local California newspaper reporter covering the first launch to nickname the unacknowledged spacecraft, "Big Bird."

Hexagon was also known by the overt Air Force program identifier of Project 467. As with Gambit, the imagery users in the Talent-Keyhole world knew the system by its camera number designator, in this case KH-9. The NRO numbered KH-9 missions using a 1200 series, 1201 to 1220.

using Titan-IIID (later upgraded to Titan 34D) LVs that inserted the satellite into a near-polar, sun-synchronous orbit with a 97-degree inclination and a typical perigee of 88 nm and apogee of 155 nm. The sun-synchronous orbit ensured that the spacecraft's orbital plane maintained the same orientation relative to the Sun and facilitated the KH-9 with imaging points on the Earth's surface at the same sun angle on each orbital pass. The shadows cast by the imaged objects on the ground thus did not change over time and the resulting photographs contained similar lighting and shadowing that could be analyzed to measure a target's height or to detect changes to frequently imaged sites or the presence of new objects (Oder, et. al., 1992; Sellers, 2005).

Operators' Corrections Ensured Hexagon's First Flight was a Success

The NRO's operators salvaged the first Hexagon mission through careful anomaly resolution. After the satellite settled into its orbit and deployed its solar panels, and command and telemetry subsystem operation commenced, the sensor began working. Very soon after, however, the flight operators began to detect trouble. The temperature of the main battery bay rose precipitously, causing concern over a potential explosion. The operator carefully monitored and controlled the sensor's scanning operations to avoid completely discharging the batteries in the main bay. While this reduced sensor usage to about one-half its designed capacity on that first mission, it did not appreciably decrease expected image taking; first missions of new systems are usually functional demonstrations to evaluate performance and make corrections and improvements, and are only secondarily intelligence missions. Carefully tracking battery voltage for the remainder of the mission, the NRO operators ensured that the first Hexagon flight completed 31 days of imaging operations and conducted 430 photo operations (Oder, Fitzpatrick, & Worthman, 1992).

Hexagon did not use the Agena as both Corona and Gambit had done, but instead incorporated power, attitude control, and orbital adjust functions into the basic spacecraft. The Hexagon spacecraft consisted of three distinct sections, forward, mid, and aft, with the forward section housing the four recovery vehicles and film take-up, the forward film-path, and the mapping-camera; the mid-section housed the sensor subsystem (see Figure 6); and the aft section contained the vehicle controls, including the satellite subsystems and the booster adapter needed to attach the vehicle to the Titan rocket. Hexagon had two mission camera systems—a panoramic camera system for its intelligence mission, and a mapping camera subsystem for its mapping mission.

Panoramic Camera

The Hexagon optical subsystem housed twin, independently controllable, stereo panoramic cameras mounted side by side on rotating optical bars. The camera optics were enclosed within a rigid structure called the optical bar assembly, and the key to the optical bar configuration was the "air bar twister."

Optical Subsystem. The optical subsystem was housed in the satellite's mid-section. Each of Hexagon's panoramic cameras featured a folded Wright optical system developed by Perkin-Elmer, with both reflecting and refracting optical elements, a 60-inch focal length, and f/3.0 aperture. The camera assembly weighed 5,375 pounds without any film loaded (the film could add up to another 2,000 pounds). The panoramic cameras used 6.6-inch, type 1414 or the thinner-base SO-208 (black and white), SO-255 (color), and occasionally SO-130 (infrared), medium-resolution film. By positioning the cameras on opposite sides of the spacecraft, Hexagon's design engineers had one camera scan forward 10 degrees on the vehicle's port side, while the second panoramic camera scanned 10 degrees to the vehicle's rear on the starboard side to produce 20 degree, convergent-stereo coverage. Throughout the Hexagon program, the NRO conducted missions containing both mono- and stereoscopic imagery.

As Hexagon photographed targets, its optical bars would rotate 360 degrees continuously, and a cylindrical drum platen would direct film across the focal plane, photographing targets from 30 degrees through a maximum of 120 degrees of each scanning rotation. The "optical bar assembly" (see Figure 7) consisted of a cylindrical housing unit that provided a mount and thermal protection for the optical elements, and facilitated the rotating motion for the system's transverse scan (Classified source, CSNR reference collection; Oder, Fitzpatrick, & Worthman, 1992).

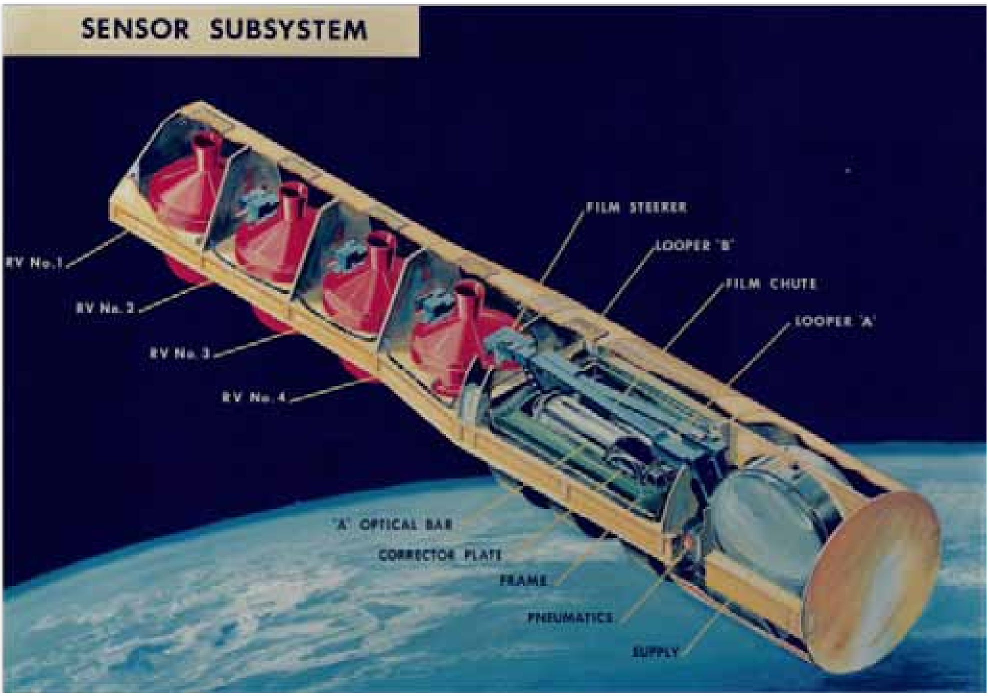

Figure 6. Hexagon Sensor Subsystem.

The "Air Bar Twister" Component. The "air bar twister" was Perkin-Elmer's (see Industrial Base attachment for a discussion of the contractors who built Gambit and Hexagon) design solution to the problem of angular changes in the high-speed film transport system. The "twister" was a twin air-bar assembly that adjusted for the twisting in the path as film traversed from Hexagon's fixed position film drive assembly to the oscillating platen assembly. The platen assembly accurately positioned the film in the focal plane as an image was exposed. The twister component pivoted to accommodate the change in angle between the film drive assembly rollers and the platen assembly rollers. The film first wrapped one twister air bar before entering the oscillating platen assembly, tracking precisely through the focal plane, and then exiting the platen assembly to wrap the other air bar and return to the film drive assembly. The gas-cushioned air bars ensured that film would move from the supply spool to the focal-plane platen without touching surfaces that might streak it or cause it to heat up and stick. There was a chamber called a "looper" that held the film slack to prevent tearing or stretching (Classified draft manuscript, CSNR reference collection; Classified source, CSNR reference collection).

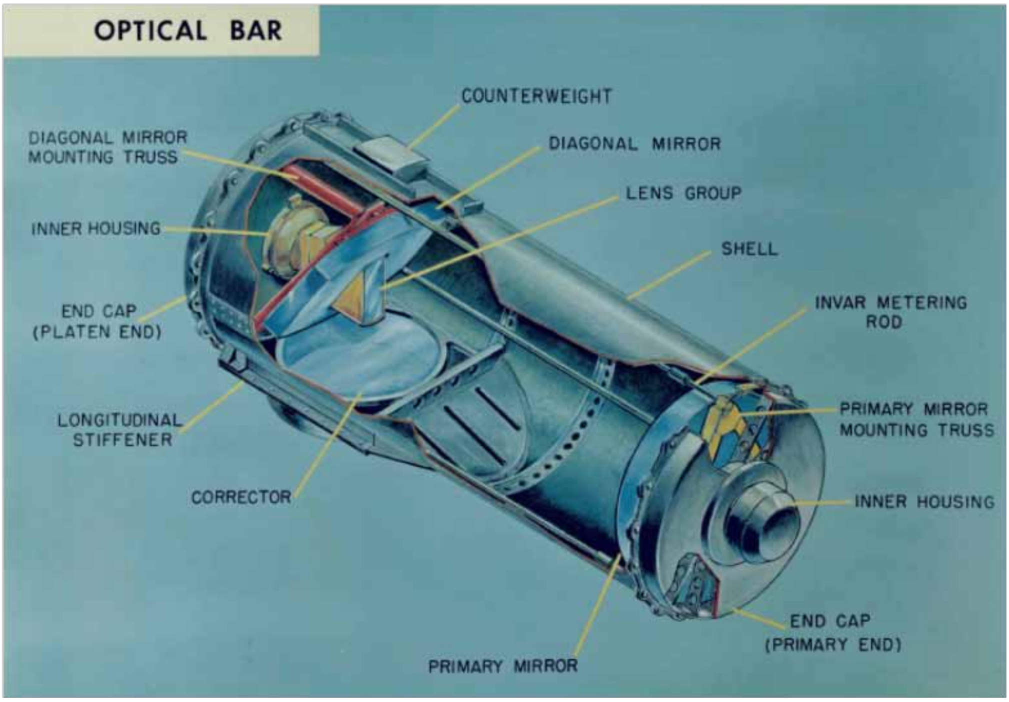

Figure 7. Hexagon Optical Bar.

Mapping Camera Subsystem (MCS)

Hexagon's mapping camera subsystem consisted of a terrain and stellar cameras, and associated hardware, and a separate recovery vehicle. The terrain camera had a 12-inch, f/6.0 metric lens and 8 elements and used 9.5-inch film to capture images that facilitated the production of medium- and large-scale maps. The stellar camera featured two 10-inch f/2.0 lens systems and 70-mm film and took pictures of stars out of each side of the orbiting vehicle to obtain metric accuracy for objects on the ground.[14] Because the MCS contained its own twin-camera system and recovery vehicle, it could operate concurrently, but also independently as a subordinate mission to the panoramic/intelligence mission. The MCS requirements called for 16 million snm of denied areas and 10 million snm of worldwide coverage annually. Prior to the first mission, the NRO planned to operate mapping cameras approximately 60 days before separating the recovery vehicle, a figure it reached just three times in the first eight missions, but by the last four missions, coinciding with the introduction of ultra-ultra-thin-base film, the mapping operations nearly doubled in length, peaking at 118 days on each of the last two missions, Missions 1215 and 1216. The MCS coverage amount steadily increased on the first three missions, from 5.9 million snm on Mission 1205 to 6.7 million snm on Mission 1207, culminating with 16.5

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[14] Both the Corona and Gambit systems used stellar cameras to photograph stars. By triangulating the fixed stars' position, the NRO could determine the satellite vehicle's precise location at the time the picture was taken. To establish accurate positions for Hexagon while in orbit, the NRO also employed a Doppler Beacon System (DBS) to get ephemeral information.

million snm on mission 1216, the last to carry a separate mapping camera[15] (Oder, et. al., 1992; Classified source, CSNR reference collection).

NRO Program Name, Overt ID	Hexagon, Program 467	Hexagon, Program 467
Camera System	KH-9	Mapping Camera Subsystem[16]
Camera Type	Panoramic	Mapping
Mission Numbers	1201 - 1220	1205 - 1216
Period of Operation	Jul 1971 - Apr 1986	Mar 1973 - Oct 1980

Table 2. Hexagon's Primary Cameras, Mission Numbers, and Period of Operation

Gambit and Hexagon's National Security Contribution

From the mid-1960s until the mid-1980s, Gambit and Hexagon collected comprehensive imagery intelligence on strategic forces and weapons systems that contributed greatly to U.S. national security planning and policymaking. Photographs always have been an information-rich source for intelligence analysts to acquire information and illustrate their findings to national security policymakers desirous to know factors such as: (1) where the enemy's military installations are, (2) how many combat forces it has and of what strength, and (3) what its economic performance might be. Collecting such photography had always been difficult and dangerous, but national reconnaissance imagery satellites superseded the limitations of prior methods, e.g., camera-carrying balloons and high-altitude reconnaissance aircraft flying over hostile territory, and removed the danger to pilots, to give the country a technological advantage in the intelligence war and a strategic edge in the broader Cold War. Gambit and Hexagon provided essential imagery coverage of a wide-range of intelligence targets, and analysis performed at imagery interpretation centers—the National Photographic Interpretation Center (NPIC – see sidebar) principally performed national-level exploitation, although the CIA, DIA, and the military services also exploited this imagery—revealed incontrovertible visual evidence that unveiled the secrets of America's Cold War adversaries.

Although the NRO primarily operated Gambit surveillance or "spotter" satellites to obtain high-resolution images of priority intelligence targets for detailed scientific and technical analysis, and Hexagon wide-area search satellites to repeatedly photograph denied territory for the discovery or negation of new military installations or activities, the operational missions encompassed sufficient complexity to complement and overlap each other. For example, although KH-9 imagery contributed almost exclusively to economic

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[15] A small percentage within each mission was redundant coverage, about 1 to 9 percent on missions for which numbers were available. The amount of redundant mission-to-mission coverage peaked at 24 percent on mission 1215 (Classified source, CSNR reference collection).

[16] Technically the mapping camera system is considered a secondary, not primary, Hexagon camera, but we included it here because Hexagon's mapping mission had such impact and the system's later block changes incorporated a panoramic camera with a solid state sensor capable of performing both the intelligence and mapping missions.

activity assessments and crop yield projections, both KH-9 and KH-8 imagery revealed to IC photo interpreters the deployment and activities of military forces that provided order-of-battle data, and uncovered the presence of new facilities and ongoing construction of ballistic missile development and deployment (Oder, Fitzpatrick, & Worthman, 1992).

During the Reagan administration, the Department of Defense drew on the vast volume of Gambit and Hexagon imagery intelligence to produce publications that helped make the case of the Soviet threat to the American public and openly demonstrate the reality of that threat to the international community. In the 1980s, the DoD published the unclassified Soviet Military Power handbook that highlighted new developments in the Soviet Union's armed forces as it was building new generations of offensive strategic and theater nuclear forces, building conventional land, sea, and air forces, and expanding its strategic defense forces. The authors of these series of publications consulted the information extracted from analysis of Gambit and Hexagon imagery in assessing the Soviet threat and making their case.

The scope of the national security contribution of these satellite reconnaissance programs is too great to cover in detail in this brief overview article. However, we can summarize their contributions in five areas: (1) assessing the Soviet strategic threat and arms control treaty compliance, (2) scientific and technical weapons analysis, (3) mapping, (4) economic forecasts, and (5) environmental and agricultural management and disaster assessment.

Assessing the Soviet Strategic Threat and Arms Control Treaty Compliance

In analyzing the Soviet strategic threat, the U.S. had to consider a number of key issues requiring technical intelligence. Among these were:

- Soviet ballistic missile development and deployment (how many the Soviets possessed, weapons characteristics, etc.)
- Soviet antiballistic missile systems, air defenses, and surface-to-air missile upgrades
- Soviet strategic bomber force

Strategic Ballistic Missiles. Much of the information that the U.S. had about Soviet missile development and deployment came from Hexagon and Gambit imagery. In general Hexagon's panoramic imagery discovered new ICBM sites or monitored activities at known locations (answering the "how many" question) and Gambit's spotting imagery provided technical insight into missile development (answering the "weapons characteristics" question). Although not an example of Gambit's highest resolution capabilities, Figure 8 shows a Soviet ICBM launch site imaged on the last KH-7 mission.[17]

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[17] As of the date of this article, KH-8 imagery remains classified and KH-9 panoramic camera imagery is under review for release.

Figure 8. KH-7 Image of Launch Site 3, Plesetsk ICBM Complex in Former Soviet Union.

By 1985 the Defense Department was concerned about Soviet development of the SA-X-12, surface-to-air missile system under development to replace the SA-4. The Soviets were designing the SA-X-12 to counter high-performance aircraft and were to have a capability against tactical ballistic missiles. The interaction of the Hexagon and Gambit missions enabled the U.S. to monitor and assess Soviet development of the army weapon system; in the 1985 edition of Soviet Military Power, the DoD published artists' sketches derived from reconnaissance imagery (See Figure 9) (U.S. DoD, 1985, p 69).

Even though by 1983 land-based ballistic missiles were the predominant delivery system for nuclear attack, the Soviets still considered bombers as a viable component of its nuclear force. The U.S. knew of the capabilities and deployment of the Soviet bomber force through analysis of Hexagon and Gambit imagery. The Backfire, which the Soviets introduced in 1974, deployed by 1983 some 100 of these long-range aircraft capable of performing nuclear strikes. The Blackjack was a new capability at the time, and it was a large, variable-geometry-wing aircraft capable of long-range subsonic cruise with supersonic high-altitude dash and subsonic/transonic low-level penetration. Through analysis of Hexagon and Gambit imagery, defense analysts determined that it could deliver both free-fall bombs and air-launched cruise missiles with intercontinental range. At the time, analysts assessed that the Blackjack would be introduced to the operational force as early as 1986 or 1987. Figure 10 shows a map that DoD published in the 1983 edition of Soviet Military Power depicting the range of Blackjack and Backfire of 2-way missions from Soviet Bases (U.S. DoD, 1983, p. 25).

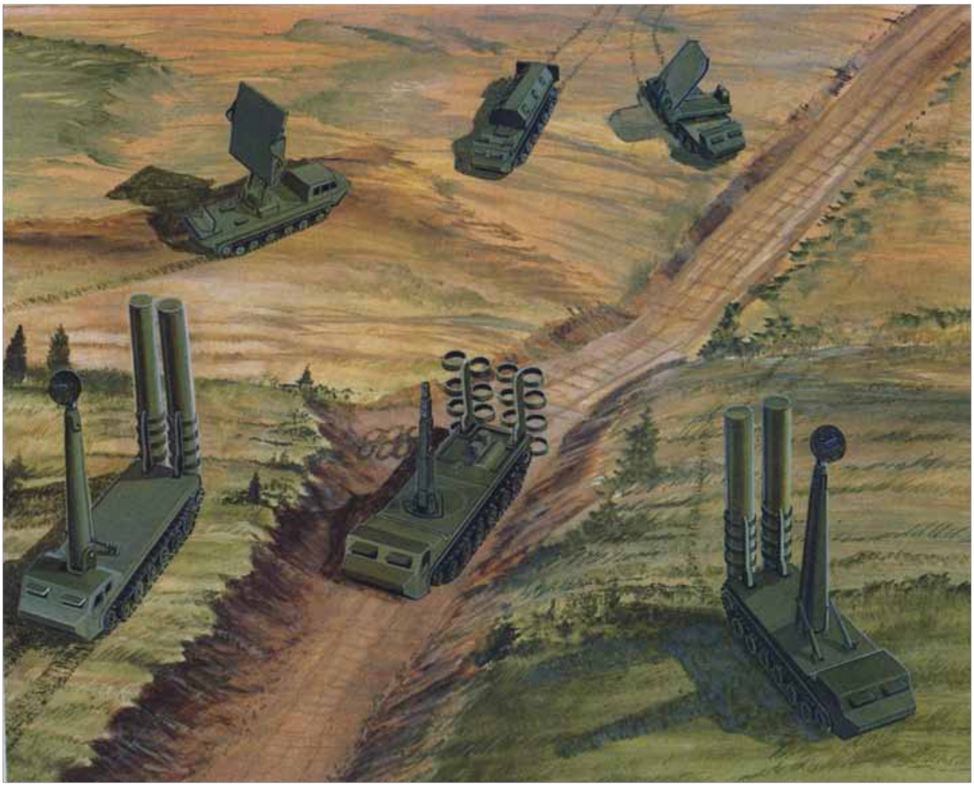

Figure 9. Illustration of Soviet SA-X-12 Air Defense System.

Arms Control Treaty Compliance. As previously stated, the by-then established capabilities of the KH-8 system (and a gracefully aging KH-4) and the expected capabilities of the KH-9 system played a significant part in the U.S. decision to sign SALT I with the Soviet Union. Hexagon's image quality and reliability, extended mission durations, and huge imagery volume returned per mission, gave U.S. officials a thorough enforcement mechanism.[18] The KH-9's comprehensive and redundant coverage allowed U.S. officials to locate and track new Soviet Intercontinental Ballistic Missile (ICBM) sites, document the dismantling of prohibited missiles, and discover new Soviet long-range bombers and ballistic-missile submarines. The KH-8 contributed to verification, too. Working in conjunction with Hexagon search missions—the NRO typically staggered the launches and missions of the two systems—the KH-8 provided the detail on targeted weapons that enabled analysts to conclude whether or not the Soviets were deploying newer military equipment (e.g., missiles) in contravention of treaty agreements. The KH-8 cameras also allowed analysts to assess the hardness of Soviet missile silos. Gambit's high-resolution imagery—and the ability to magnify original negatives up to 100 times—enabled U.S. officials to track arms shipments through a systematic measuring and cataloguing of shipping containers (Oder, et. al., 1991).

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[18] There was apparently some skepticism about relying on space assets so heavily. In particular, then Director of Central Intelligence Richard Helms was said to be concerned whether satellite photography would be sufficient to detect "Potemkin Village" deceptions with which the Soviets would attempt to circumvent missile deployment limits (Classified source, CSNR reference collection).

Scientific and Technical Weapons Analysis

The very high resolution attainable by the KH-7 and KH-8 cameras made Gambit the first imaging satellite to make significant contributions to "technical" intelligence. Using Gambit imagery, analysts were able not only to make informed intelligence judgments on Soviet weapons deployments, military order of battle, and camouflage and concealment practices, but also to perform scientific and technical (S&T) analysis of precisely targeted objects and facilities, among them strategic missiles, aircraft, ballistic missile-launching submarines, communication vehicles and equipment, military units, and advanced weapons facilities. In the early 1980s the Defense Department was concerned about Soviet shipbuilding, which was providing their Navy with the world's largest submarine force. The Hexagon and Gambit systems were watching this construction at the Severodvinsk Shipyard[19] on the White Sea. (See Figure 11 for a KH-9 image of a typhoon class submarine at Severodvinsk.) Based upon Hexagon and Gambit imagery, the DoD published an artist's concept of the second unit of the Soviets' then newest OSCAR-Class nuclear-powered cruise missile attack submarine as it was fitting out at the shipyard (Figure 12) (U.S. DoD, 1983, p. 71).

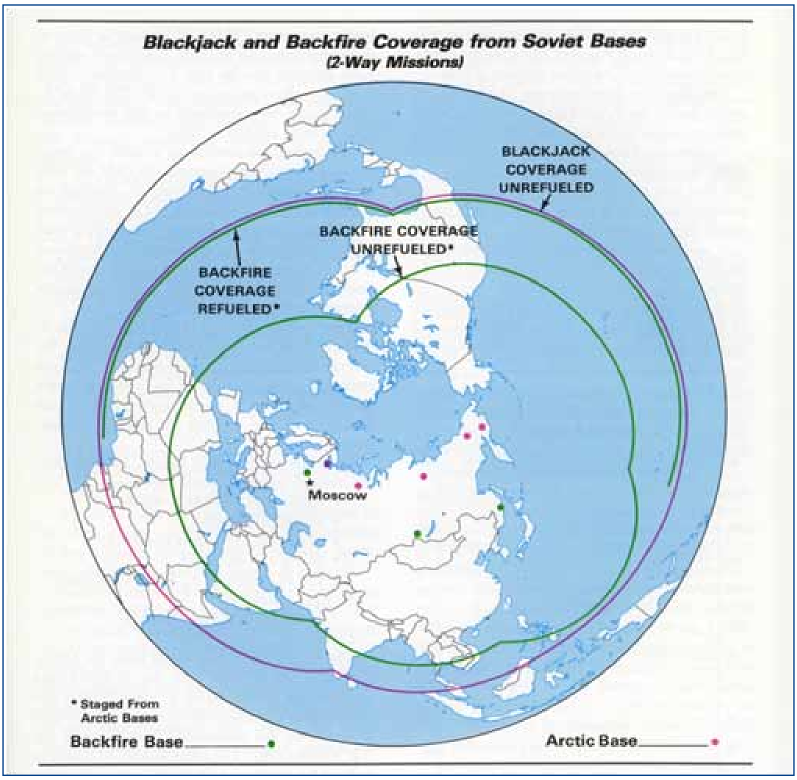

Figure 10. Range of Soviet Strategic Bombers, Blackjack and Backfire.

The KH-8's capability, and in turn the analyst's interpretative ability, dramatically improved over the life of the program. Upon its first launch in July 1966, the Gambit-3 satellite provided immediate improvements over its Gambit-1 predecessor: during the Gambit-3's 11-month "development flight program" (M4301 – 4306), the Defense Intelligence Agency (DIA) reported that it could identify and count individual military vehicle types and models. The final KH-8 camera achieved remarkable visual acuity and accurate mensuration data. Looking at a NIIRS-5 (see sidebar below) or better photograph—a standard that Gambit cameras regularly exceeded—even "the non-photointerpreter would find it easier to believe what he was being told; he could actually identify targets in the imagery" (Oder, Fitzpatrick, and Worthman, 1991, p. 123). Gambit-provided S&T information probably saved the U.S. millions of dollars that otherwise would have been used to develop and produce counterweapons for a military worst-case scenario (Smith, 2002; Oder, Fitzpatrick, & Worthman, 1991).

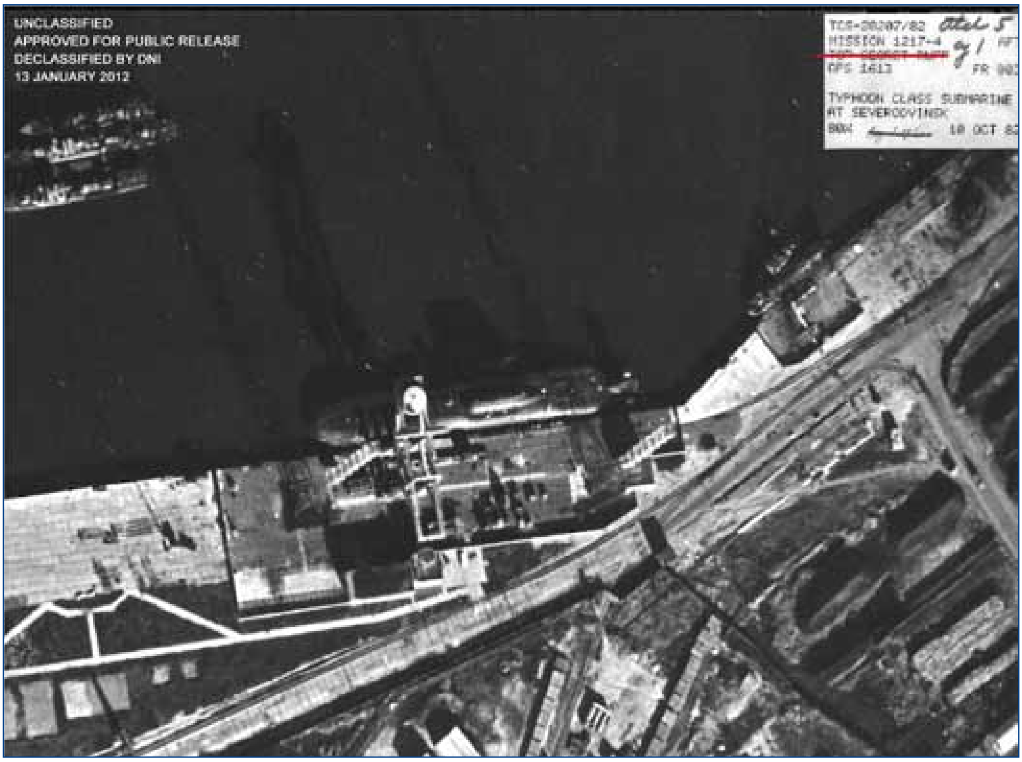

Figure 11. KH-9 (M1217) Image of a Typhoon Class Submarine at Severodvinsk.

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[19] Severodvinsk Shipyard was one of five at the time in the U.S.S.R. providing its navy with submarines.

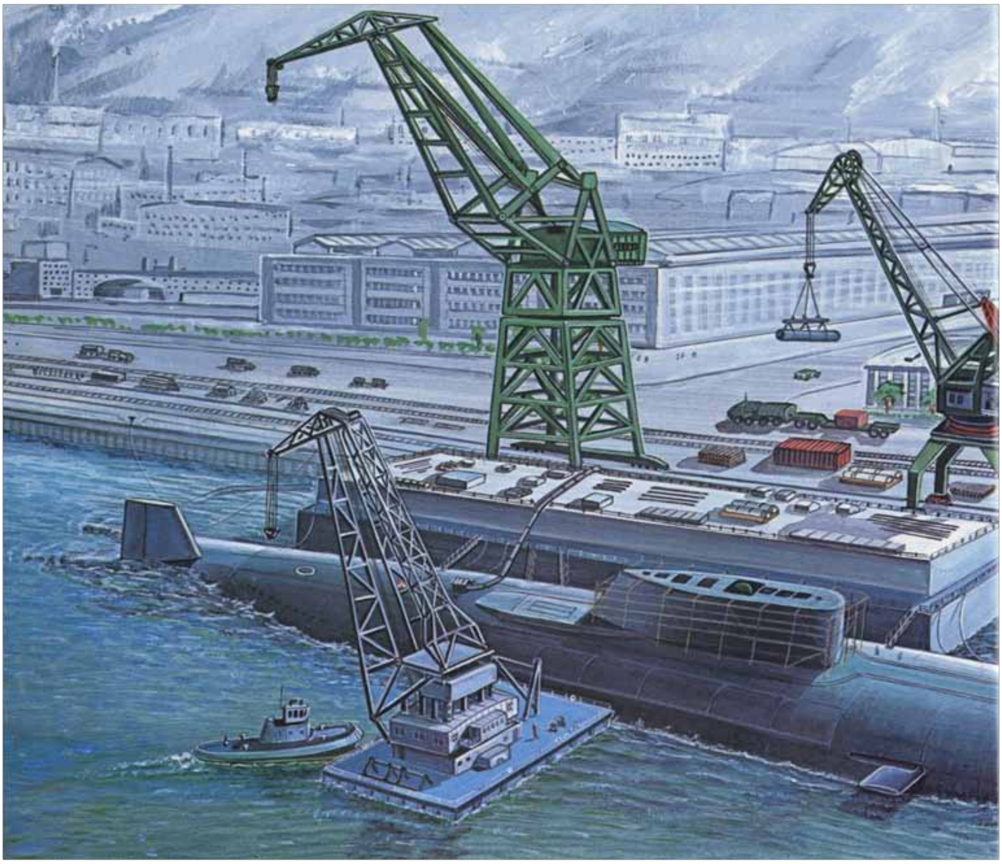

Figure 12. Illustration of Soviet Oscar-class Nuclear-powered Attack Submarine at Severodvinsk Shipyard.

Mapping

Beginning on the fifth Hexagon mission (Mission 1205), the NRO incorporated a Mapping Camera Subsystem (MCS), consisting of terrain and stellar camera lenses. Hexagon mapping imagery contributed to the establishment of a worldwide system of accurate ground coordinates for a wide variety of military, civilian, and intelligence programs. The Defense Mapping Agency (DMA) produced many products based on KH-9 MCS photography, including: (1) Medium- and small-scale maps and charts (topographic, aeronautical, and hydrographic maps/charts production at 1:200,000 and smaller scales); (2) Large-scale (1:50,000) topographic line maps; and (3) Digital terrain and feature data used to support advance weapons systems targeting (digital terrain elevation data). From the MCS-collected data, in the late-1970s the U.S. Geological Survey also constructed maps for the National Petroleum Reserve and Alaskan pipeline projects.

A New Imagery Evaluation System – NIIRS

Prior to the early 1970s, photointerpreters of satellite imagery used a subjective scale to rate image quality. Analysts would judge imagery to be "excellent," "good," "fair," or "poor," but these descriptions failed to assess the degree to which the product satisfied specific intelligence requirements. After John Hicks assumed directorship of the National Photographic Interpretation Center (NPIC) in 1973, he set about establishing a national imagery rating system that was independent of the collection system. Although the work had begun as a SALT Accountability Task Team with NPIC, the Committee on Imagery Requirements & Exploitation (COMIREX),* and the CIA Offices of Imagery Analysis and Strategic Research participating, the effort accelerated after the first few successful Hexagon missions, a system which challenged a consistent rating scheme due to the KH-9's wide variation in image quality. In 1973 the SALT Accountability Task Team proposed a revised scale and COMIREX approved it to be used to evaluate KH-9 Mission 1207 that November. The initial revised scale had categories ranging from 0 to 7, based on an image's "information potential for intelligence purposes," and in March 1974, the NPIC produced a refined scale with categories 0 to 9. After validating the new ratings standards on targets imaged on KH-9 missions 1207 through 1209, the COMIREX approved the new scale, called the "National Image Interpretability Rating Scale," or NIIRS. Sometime after September 1974 the USIB began to promote the use of NIIRS throughout the Community, and photointerpreters in all departments (NPIC, DIA, Army, Navy, Air Force) received specialized training on the new interpretive standards (Oder, Fitzpatrick, & Worthman, 1991).

* The COMIREX was a DCI committee responsible for identifying the intelligence collection and exploitation of national reconnaissance imagery assets. It also had responsibilities for associated policy and R&D.

In all, users of KH-9 MCS material generated over 70,000 positional values of various targets. Figure 13 below shows a Hexagon MCS image of Moscow taken in 1979. The MCS collection assisted U.S. military targeting of newly discovered installations that could now be affixed positions on DMA maps. On the last three successful Hexagon missions, the NRO flew a block change satellite vehicle that included a solid state stellar camera system that gave the requisite metric accuracy to panoramic imagery to make the MCS unnecessary. Thus, the DMA could create precise maps from panoramic imagery, greatly improving Hexagon's utility in the last three vehicles (Classified source, CSNR reference collection).

Although of lesser importance, the KH-7 system featured a secondary, 1.5-inch frame mapping camera. Though its use was limited and resolution relatively poor (400–500 feet at a nominal photo scale of 1:3,886,000), the KH-7 secondary mapping camera provided the Department of Defense (DoD) with data for production of 1:50,000 scale maps. The KH-8 had a 3-inch frame mapping camera, capable of 66-foot resolution at a nominal photo scale of 1:1,837,444. The Gambit-3 satellite was also adapted for operations in a higher orbit that permitted dual use or dual-mode operations as a search satellite. Still, Gambit's primary mission objective was to capture high-resolution images of priority targets (Classified source, CSNR reference collection; NIMA, 2002).

Figure 13. KH-9 MCS Image of Moscow, Russia.

Economic Forecasts

Another important use for KH-9 MCS imagery was in forecasting economic production of targeted adversary countries. Hexagon's expansive coverage using both black-and-white and color and color/infrared film contributed to more accurate forecasts. Images of built-up industrial areas revealed the production of heavy metals, oil, or natural gas, and analysts could also derive a target area's nuclear and conventional power capacities. The Hexagon MCS also proved well adapted to collecting large-acre crop inventory intelligence data that allowed U.S. policymakers to track Soviet economic development and estimate Soviet and Chinese grain production (Oder, Fitzpatrick, & Worthman, 1992).

Environmental and Agricultural Management and Disaster Assessment

The U.S. Departments of Agriculture, Commerce, and Interior used Hexagon MCS imagery for environmental monitoring, agricultural management and land inventories, and disaster assessment. These organizations derived other products that supported their missions from the imagery, exemplifying Hexagon's additional value to the country. For example, the Environmental Protection Agency used KH-9 MCS imagery to support their environmental monitoring program, and the Soil Conservation Services used the imagery to update county soil survey maps. The National Ocean Survey was another user of MC&G data, with which it revised nautical and aeronautical charts. Finally, the U.S. Forest Service consulted Hexagon MCS imagery to take land area inventories as part of the National Forest Management Act of 1976. American officials also used Hexagon photography to assist with damage assessments and recovery efforts following natural disasters. The NRO has expanded on this use for satellite imagery, and in the 21st century the mission of national reconnaissance assets includes acknowledged support to disaster recovery (Oder, Fitzpatrick, & Worthman, 1992).

Conclusion

The Hexagon and Gambit photoreconnaissance satellites were two landmark intelligence systems that for more than two decades provided U.S. leadership with invaluable foreign intelligence on critical targets and geodetic data for maps and charts having military, national security, and civil planning applications. The two systems' combined capabilities provided reliable technical means for U.S. officials to enforce international arms treaties that helped control the pace of nuclear escalation. The research, testing, and development investment in the spacecraft, payload, film-recovery vehicles, and other system components also helped advance emerging space technology and laid the groundwork for innovations in other technical fields. In addition, the NRO derived management, engineering, and operational lessons from the programs that proved beneficial in developing successor satellite systems. Those successor satellites ensured that Intelligence Community (IC) agencies thereafter would have access to a near-continual stream of imagery data for exploitation and analysis, with which they could make informed assessments based on unambiguous visual evidence (Oder, et. al., 1991; Oder, et. al., 1992).

The National Photographic Interpretation Center

The NPIC evolved from the Central Intelligence Agency's (CIA) Photo Intelligence Division of the Office of Research and Reports, a 13-person operation located in the M Building in the Foggy Bottom neighborhood of Washington, D.C. In the mid-1950s, the primary photo interpretation mission was exploiting aerial reconnaissance photography, especially the U-2 after its maiden flight on 04 July 1956, and developing a photo intelligence database to satisfy substantive technical intelligence requirements. With the advent of satellite photoreconnaissance, the need grew for a national-level, interagency capability to analyze overhead photography, and in 1961, President Eisenhower established the charter for the renamed NPIC. The first NPIC director was Art Lundahl, who had been a photointerpreter with the U.S. Navy in the Pacific Theater of World War II, and later the Chief of the Photogrammetry Division of the Naval Photographic Interpretation Center (NAVPIC).

By the time of the first Gambit launch in 1963, the NPIC had grown in size and importance to become a multi-departmental organization of more than 1,000 employees hailing from CIA, the Defense Intelligence Agency (DIA), and U.S. military intelligence organizations. The growth necessitated relocation to what would become the Center's longtime home in Building 213 at the Washington Navy Yard. With the "quantum leaps" in satellite imagery collection technology that were occurring by the early 1970s—including the initiation of Hexagon operations, the continuing Gambit missions, and the electro-optical satellites then in development—the CIA transferred the NPIC from the Directorate of Intelligence to the Directorate of Science and Technology, where it received additional funding resources necessary to upgrade its exploitation equipment and facilities. The NPIC provided the Intelligence Community, State Department, Department of Defense, military commands, and civil agencies with photo analysis for the next 23 years.

The NPIC was decommissioned in 1996 and consolidated with other organizations as the National Imagery and Mapping Agency (NIMA). The NIMA became the National Geospatial-Intelligence Agency (NGA) in 2003.

Source: (Brugioni & Doyle, 1997; classified manuscript, CSNR reference collection).

Gambit's Legacy

In August 1984, as the National Reconnaissance Office (NRO) prepared to recover the last film bucket released by the Gambit satellite system, President Ronald Reagan conveyed the country's gratitude for the contributions made by the Gambit program. In a memo titled "Commendation to the Gambit Program," Reagan wrote:

> *The technology of acquiring high quality pictures from space was perfected by the GAMBIT Program engineers; GAMBIT photographic clarity has yet to be surpassed. Through the years, intelligence gained from these photographs has been essential. . . . [and] have greatly assisted our arms monitoring initiatives. They have also provided vital knowledge about Soviet and Communist Bloc scientific and technological military developments, which is of paramount importance in determining our defense posture.*

(quoted in Oder, et. al., 1991, pp. 117-118).

Hexagon's Legacy

Hexagon's development took longer and cost more than any national reconnaissance system that preceded it—one of the most complex mechanical devices ever put into orbit, the satellite vehicle had myriad, sophisticated subsystems with many moving parts that proved exceedingly challenging to integrate—but it met or exceeded all of the intelligence requirements established at program initiation, and it would be difficult to refute the assertion that Hexagon's many national security benefits justified the high dollar cost. Throughout its 13-year operational lifespan, the system monitored the development and deployment of ICBMs, long-range bombers, ABMs, and ballistic-missile submarines, to name just a few recurring target sets. The 48,000 linear feet of usable mapping data it returned, resulting in total MCS ground coverage of some 104 million snm, added another vital element to Hexagon's immense national security contribution.

Hexagon's mapping camera provided the mapping community—both for foreign and domestic mapping requirements—with imagery to produce geospatial products at a significantly higher accuracy than the earlier KH-5 mapping system. It provided better than a four-fold improvement in accuracy, and more than a ten-fold improvement in resolution, over the former KH-5 mapping camera. The geodetic data consisted of precise geographic positioning, elevation, and similar information. It gave users accurate point locations for air, sea, and ground operations. The information derived from the mapping imagery could produce accurate maps at a 1:200,000 scale. It also had applications for tactical and strategic weapons systems target planning (NIMA, 2002).

At the end of 1973, after the NRO's Program B had transferred Hexagon program control to Program A,[20] the CIA's Audit Staff reviewed the CIA's Office of Special Project's (OSP) management of the program. The Audit Staff concluded that Hexagon had been a tremendous technical success, but something of a financial disappointment. The design goal for Hexagon had been to produce one search and surveillance system with the capability to undertake the missions of both Corona and the KH-7 Gambit system, thus saving money by operating one system rather than two. Although Hexagon exceeded the technical design goal, it also greatly overran the proposed costs, leading the Audit Staff to speculate that had the final costs been known during development, the Community might have elected to scale back Hexagon's technical capabilities or to cancel the program and further improve Corona instead. The OSP's program assessment at the time was less speculative and perhaps more to the point: "There is no other photographic satellite system which has the combination of resolution, swath, mission duration, and camera system flexibility possessed by the Hexagon system. If for some reason the U.S. were forced to rely upon only one system, Hexagon would be that system" (quoted in classified draft manuscript, CSNR reference collection).

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[20] In 1962, the NRO established an alphabetic program office structure, with offices A through D. Each office received staffing and human resources support from its parent organization, which were as follows: NRO Program A–U.S. Air Force; Program B–CIA; Program C–U.S. Navy; Program D (until 1974)–Air Force and CIA.

Declassification

These satellite reconnaissance programs remained classified until 2011, the year NRO celebrated its 50th Anniversary. On 2 June 2011, DNRO Bruce Carlson signed guidance declassifying most programmatic elements of the NRO's Gambit and Hexagon satellite reconnaissance programs. While the declassified information included program names, mission numbers, operating dates, certain hardware and details about the programs, the NRO continues to protect some information still considered to be sensitive.

The decision to declassify these programs was a slow and deliberate process that took some ten years. The Center for the Study of National Reconnaissance (CSNR) conducted a series of assessments of the risks of declassifying program details, and it consulted with experts across the Intelligence Community. The NRO's Information Access & Release Team (IART) carefully developed a declassification guide and conducted the necessary coordination within the Intelligence Community.[21] After the decision, the NRO applied the declassification according to its phased implementation plan. This painstaking approach underscored that these programs produced state-of-the-art capabilities that, even in 2011, remained impressive. As one of the authors remarked in the foreword to a compendium of program documents, "National reconnaissance is too valuable of a national treasure for its secrets to be lost to compromise" (quoted from Outzen, 2012, p. IV).

Even though these programs remained highly sensitive and classified over the past 27 years, Presidents of the United States made public references to their value.

President Lyndon Johnson, in March 1967, stated,

> *. . . we've spent thirty-five or forty billion dollars on the space program. And if nothing else had come out of it except the knowledge we've gained from space photography, it would be worth ten times what the whole program cost. Because tonight we know how many missiles the enemy has . . . (Soory, 1967)*

Johnson made this off-the-record statement to demonstrate that the knowledge the U.S. gained from satellite reconnaissance confirmed that initial U.S. estimates of the Soviet threat were too high, which enabled the country to reallocate funds to capabilities it needed to build.

President Jimmy Carter on 1 October 1978 stated,

> *Photoreconnaissance satellites have become an important stabilizing factor in world affairs in the monitoring of arms control agreements. They make immense contribution to the security of all nations. (p. 1686).*

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[21] The Center for the Study of National Reconnaissance (CSNR) is a component of the Business Plans and Operations at the National Reconnaissance.

He made this statement during a speech at the Kennedy Space Center to share his confidence in the "national technical means" of photosatellite reconnaissance in order to engender public support for SALT II.

The Gambit and Hexagon systems impressed Presidents and provided their national security teams with critical intelligence about Cold War adversaries. They were revolutionary by the standards of the time and continued to be impressive for a least a quarter of a century after their termination. They laid the technological groundwork and were the inspiration for the next generation of imaging reconnaissance satellites, NRO's near-real-time imaging systems. The Gambit and Hexagon operations previewed in the mid-20th century what would become commonplace in 2011 at the NRO's 50th Anniversary date—satellite reconnaissance imagery routinely incorporated into intelligence and military operations, unclassified commercial space imagery available for anyone to purchase, and Google Earth where space imagery can be viewed anywhere in the world on an Internet computer.

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Attachments: Gambit and Hexagon Mission Summaries

Launch Date	Mission No. & Length	Camera Designator	Mission[22] Success	Remarks
1963				
12 Jul.	4001 (1 day)	KH-7	Yes	1st successful high-resolution imagery mission
06 Sep.	4002 (2 days)	KH-7	Yes	Resolution better than 3 ft.
25 Oct.	4003 (2 days)	KH-7	Yes	First flight to use color film
18 Dec.	4004 (1 day)	KH-7	No	Orbital-control gas lost; no usable film recovered
1964				
25 Feb.	4005 (2 days)	KH-7	No	No usable film due to anomalous yaw
11 Mar.	4006 (3 days)	KH-7	Yes	First flight with stellar-index camera; conducted low altitude experiments (70 n.m.) for 7 revs.
23 Apr.	4007 (4 days)	KH-7	Yes	Imaged two days at low orbit; 209 targets imaged
19 May	4008 (1 day)	KH-7	Yes	Mission limited to 1 day due to vehicle instability
06 Jul.	4009 (2 days)	KH-7	No	Attitude control problems; no targets covered
14 Aug.	4010 (5 days)	KH-7	Yes	Electrical/programmer issues impaired resolution
23 Sep.	4011 (4 days)	KH-7	Yes	Focus error and gas leak impaired resolution
08 Oct.	4012 (0 days)	KH-7	No	Agena failure; satellite did not reach orbit
23 Oct.	4013 (4 days)	KH-7	No	Re-entry problem; RV lost
04 Dec.	4014 (1 day)	KH-7	Yes	Power issue; mission aborted on revolution 18
1965				
23 Jan.	4015 (4 days)	KH-7	Yes	
12 Mar.	4016 (4 days)	KH-7	Yes	
28 Apr.	4017 (5 days)	KH-7	Yes	Diagnostic instrumentation added
27 May	4018 (5 days)	KH-7	Yes	1st mission with over 1,000 targets covered
25 Jun.	4019 (1 day)	KH-7	No	Massive short circuit; no targets covered
12 Jul.	4020 (0 days)	KH-7	No	Atlas failure; no orbit
03 Aug.	4021 (4 days)	KH-7	No	Power converter failure; no targets covered
30 Sep.	4022 (4 days)	KH-7	Yes	1st mission with better than 2 ft. resolution
08 Nov.	4023 (1 day)	KH-7	Yes	Loss of control gas, stability; mission lasted 1 day
1966				
19 Jan.	4024 (5 days)	KH-7	Yes	First successful use of color film
15 Feb.	4025 (5 days)	KH-7	Yes	
18 Mar.	4026 (6 days)	KH-7	Yes	
19 Apr.	4027 (6 days)	KH-7	Yes	1st flight with 2,000+ targets covered (2,010)
14 May	4028 (6 days)	KH-7	Yes	1st successful night photography
03 Jun	4029 (6 days)	KH-7	Yes	
12 Jul.	4030 (8 days)	KH-7	Yes	Longest mission to date (8 days)
29 Jul.	4301 (6 days)	KH-8	Yes	1st Gambit-3 mission; better than 2 feet GRD
16 Aug.	4031 (8 days)	KH-7	Yes	
16 Sep.	4032 (7 days)	KH-7	Yes	
28 Sep.	4302 (7 days)	KH-8	Yes	
12 Oct.	4033 (8 days)	KH-7	Yes	
02 Nov.	4034 (7 days)	KH-7	No	Pyrotechnic/door problem; no camera operation
05 Dec.	4035 (8 days)	KH-7	Yes	
14 Dec.	4303 (8 days)	KH-8	Yes	1st use of ultra-thin base film (5,000 ft.); ESTAR ultra-thin base had thickness of 1.5 + 0.1 mils

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[22] Mission success can be a subjective measurement, but for the purposes of this table, an unsuccessful mission indicates one or more of three conditions: 1) the satellite failed to reach orbit; 2) the NRO failed to recover the film; or 3) the Intelligence Community determined that the film recovered contained no useful intelligence imagery.

Launch Date	Mission No. & Length	Camera Designator	Mission Success	Remarks
1967				
02 Feb.	4036 (8 days)	KH-7	Yes	Prime command system failed, revolution 126
24 Feb.	4304 (8 days)	KH-8	Yes	
26 Apr.	4305 (0 days)	KH-8	No	Second stage failure; failed to reach orbit
22 May	4037 (8 days)	KH-7	Yes	Best ever KH-7 resolution
04 Jun.	4038 (8 days)	KH-7	Yes	Last KH-7 flight; equaled best resolution
20 Jun.	4306 (10 days)	KH-8	Yes	1st Gambit mission lasting 10-days
16 Aug.	4307 (10 days)	KH-8	Yes	More than 2,000 targets covered (2,091)
19 Sep.	4308 (10 days)	KH-8	Yes	
25 Oct.	4309 (10 days)	KH-8	Yes	
05 Dec.	4310 (11 days)	KH-8	Yes	
1968				
18 Jan.	4311 (10 days)	KH-8	No	Parachute failed; RV not recovered
13 Mar.	4312 (10 days)	KH-8	Yes	Roll joint capable of 2,250 maneuvers installed
17 Apr.	4313 (10 days)	KH-8	Yes	New high of 2,658 targets covered
05 Jun.	4314 (10 days)	KH-8	Yes	Use of shortened photographic burst times (conserved film and increased number of targets)
06 Aug.	4315 (10 days)	KH-8	Yes	More than 3,000 targets covered (3,058)
10 Sep.	4316 (10 days)	KH-8	Yes	Redundant attitude control system installed
06 Nov.	4317 (10 days)	KH-8	Yes	
04 Dec.	4318 (7 days)	KH-8	Yes	Mission cut short; attitude control problems
1969				
22 Jan.	4319 (10 days)	KH-8	Yes	Agena inserted into higher than usual orbit; Soviet satellite Cosmos 264 made a close pass
04 Mar.	4320 (10 days)	KH-8	Yes	
15 Apr.	4321 (10 days)	KH-8	Yes	
03 Jun.	4322 (10 days)	KH-8	Yes	More than 4,000 targets covered (4,032)
23 Aug.	4323 (15 days)	KH-8	Yes	1st block-II vehicle; 1st dual-RV system
24 Oct.	4324 (14 days)	KH-8	Yes	Agena velocity meter burned to depletion; higher apogee resulted in some photography loss
1970				
14 Jan.	4325 (11 days)	KH-8	Yes	RV-2 parachute failed, lost RV-2
15 Apr.	4326 (14 days)	KH-8	Yes	
25 Jun.	4327 (11 days)	KH-8	Yes	Command programmer malfunction; RV-2 lost
18 Aug.	4328 (16 days)	KH-8	Yes	RV-2 ejected after 16 days
23 Oct.	4329 (18 days)	KH-8	Yes	
1971				
21 Jan.	4330 (18 days)	KH-8	Yes	1st test for atmospheric survivability of spent satellites suggested debris likely not recoverable
22 Apr.	4331 (19 days)	KH-8	Yes	
15 Jun.	1201 (31 days)	KH-9	Yes	1st Hexagon mission; RV-1, RV-3 parachutes failed; RV-1 recovered from water, RV-3 lost
12 Aug.	4332 (22 days)	KH-8	Yes	1st mission of R-5 lens (175-in.) system; new corrector lens with improved performance
23 Oct.	4333 (24 days)	KH-8	Yes	
1972				
20 Jan.	1202 (39 days)	KH-9	Yes	Film broke in Camera B at end of RV-2; the 20-days remaining returned monoscopic coverage
17 Mar.	4334 (24 days)	KH-8	Yes	
20 May	4335 (0 days)	KH-8	No	Pneumatic regulator in Agena failed, resulting in total loss; satellite debris recovered in England

Launch Date	Mission No. & Length	Camera Designator	Mission Success	Remarks
1972 (continued)				
07 Jul.	1203 (57 days)	KH-9	Yes	Most coverage capture in a single mission, 65 million sq. nm
01 Sep.	4336 (27 days)	KH-8	Yes	Last Gambit-3, block-II flight.
10 Oct.	1204 (68 days)	KH-9	Yes	Featured on-orbit image motion compensation
21 Dec.	4337 (31 days)	KH-8	Yes	1st block-III flight; new roll joint capable of 18,000 maneuvers
1973				
09 Mar.	1205 (63 days)	KH-9	Yes	1st Hexagon with mapping camera system; all RVs recovered in mid-air
16 May	4338 (28 days)	KH-8	Yes	
26 Jun.	4339 (0 days)	KH-8	No	Agena main tank ruptured; no orbit
13 Jul.	1206 (74 days)	KH-9	Yes	Color film and 500 ft. of near-IR film used
27 Sep.	4340 (30 days)	KH-8	Yes	
10 Nov.	1207 (102 days)	KH-9	Yes	1st block-II panoramic camera and SBA[23]
1974				
13 Feb.	4341 (30 days)	KH-8	Yes	
10 Apr.	1208 (105 days)	KH-9	Yes	All objectives satisfied; RV-1 water recovery
06 Jun.	4342 (46 days)	KH-8	Yes	block changes; TGS says Block-IV on 4348
14 Aug.	4343 (45 days)	KH-8	Yes	
29 Oct.	1209 (129 days)	KH-9	Yes	All mission objectives satisfied
1975				
18 Apr.	4344 (46 days)	KH-8	Yes	First Titan (LV) low-level shutdown sensor
08 Jun.	1210 (120 days)	KH-9	Yes	Power relay failure impaired mapping function
09 Oct.	4345 (50 days)	KH-8	Yes	
04 Dec.	1211 (116 days)	KH-9	Yes	Aft camera failed on day 20; resumed monoscopic operations with RV-4
1976				
22 Mar.	4346 (56 days)	KH-8	Yes	
08 Jul.	1212 (154 days)	KH-9	Yes	
15 Sep.	4347 (51 days)	KH-8	Yes	
1977				
13 Mar.	4348 (69 days)	KH-8	Yes	Final block change; 1st dual-platen camera with 9- and 5-in. film and improved film drive
27 Jun.	1213 (180 days)	KH-9	Yes	1st block-III vehicle; longest mission to date
23 Sep.	4349 (73 days)	KH-8	Yes	
1978				
16 Mar.	1214 (177 days)	KH-9	Yes	Used ultra-ultra-thin base film (1.2 + 0.1 mils)
1979				
16 Mar.	1215 (188 days)	KH-9	Yes	
28 May	4350 (90 days)	KH-8	Yes	Best resolution ever achieved

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[23] SBA=satellite basic assembly.

Launch Date	Mission No. & Length	Camera Designator	Mission Success	Remarks
1980				
18 Jun.	1216 (258 days)	KH-9	Yes	Record mission length; last mission flown with mapping camera
1981				
28 Feb.	4351 (110 days)	KH-8	Yes	
1982				
21 Jan.	4352 (119 days)	KH-8	Yes	Only dual-mode mission; RV-1 lost
11 May	1217 (203 days)	KH-9	Yes	1st mission with solid-state stellar sensor; NRO recovered RVs-2, 3, and 4 from water
1983				
15 Apr.	4353 (126 days)	KH-8	Yes	Longest duration Gambit-3 mission: 126 days; 49,372 targets covered
20 Jun.	1218 (270 days)	KH-9	Yes	Longest duration Hexagon mission: 276 days, including "solo" flight; 303,527 ft. of film
1984				
17 Apr.	4354 (116 days)	KH-8	Yes	Last Gambit-3 mission;
25 Jun.	1219 (108 days)	KH-9	Yes	Command system problem ended mission early; RV-4 not used
1986				
18 Apr.	1220 (0 days)	KH-9	No	Titan booster failure; entire mission lost

Source: (Oder, Fitzpatrick, & Worthman, 1991; Oder, Fitzpatrick, & Worthman, 1992)

Industrial Base Support to Gambit and Hexagon Programs

Hexagon and Gambit were built by contractors with extensive space systems experience. Some of the nation's best scientists and engineers developed, or consulted on, Hexagon and Gambit; indeed, the history of complex national reconnaissance satellites demonstrates how these programs have benefitted from the contributions of innovative and forward-thinking individuals and companies. A core group of companies formed what became a robust space industrial base that steadily grew in size and capability after the advent of ballistic missile development in the 1950s. The complexity and compartmented sensitivity of national reconnaissance programs ensured that NRO programs drew upon the resources of a recurring group of experienced contractors who had built satellites and space components before, including Lockheed Missiles and Space, General Electric, Itek, Eastman Kodak, Perkin-Elmer, McDonnell Douglas, Martin Marietta, Thompson-Ramo-Wooldridge (TRW), Fairchild Camera and Instrument Corporation, Douglas Aircraft Company, as well as the not-for-profit advisory organizations, The Aerospace Corporation and RAND. As the NRO increased the number and type of satellites being developed, and its engineers produced ever larger and more complex payloads, the companies' number of employees also grew dramatically. For example, Perkin-Elmer saw its number of employees developing the sensor subsystem on Hexagon, including sub-contractors, grow from 150 to 700 (Oder, Fitzpatrick, & Worthman, 1992; McDonald, 1995).

With each of the different contracting companies being responsible for separate system components, which they developed individually in secure facilities located quite literally from East Coast to West Coast of the U.S., it could have been the proverbial "recipe for disaster." The unifying vision and management of the NRO program offices, combined with a "mission-first" approach, even among competing contractors, ensured program success. The contractors all worked on a coordinated schedule, consulting Interface Control Documents (ICDs) that helped manage the overall system configuration and the connections between the sub-components to ensure performance specifications were met after assembly. The ICDs also served as technically binding agreements on the responsibilities of each company. The principal contractors that developed, built, and tested the Gambit and Hexagon satellite systems are listed below.

Principal Contractors on Gambit Program:

Lockheed Missiles and Space Company — Satellite control system, Agena spacecraft
Eastman Kodak — Photographic payload section
Martin-Marietta — Titan-IIIB booster vehicle and launch support
General Electric — Command subsystem and reentry vehicles

[Source: Oder, et. al., 1991, p. 104]

Principal Contractors on Hexagon Program:

Lockheed Missiles and Space Company — Satellite basic assembly and system integration
McDonnell Douglas Astronautics Company — Mark 8 reentry vehicle (pan film recovery)
General Electric Company, Aerospace Electronics Systems Dept. — Extended system command
Thompson-Ramo-Wooldridge Corporation — Software to select scan modes
Itek Corporation Optical Systems Division — Mapping camera subsystem
GE, Reentry Systems Division — Mark V Reentry vehicle
Aerospace Corporation — General systems engineering
Perkin-Elmer Corporation — Sensor subsystem

[Source: Oder, et. al., 1992, pp. 242-243]