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Center for the Study of
National Reconnaissance

Editorial Staff

The Center for the Study of National Reconnaissance (CSNR) publishes *National Reconnaissance–Journal of the Discipline and Practice* for the information, education, and use of the broader national security community, especially those government and contractor personnel who are involved with national reconnaissance. Our objective is to promote dialogue among these professionals and to identify lessons for them by facilitating a synthesis of the technical, operational, and policy components that define and shape the enterprise of national reconnaissance.

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Editor's Commentary

This spring 2012 unclassified special issue of *National Reconnaissance: Journal of the Discipline and Practice* spotlights the Gambit and Hexagon photosatellite reconnaissance programs. These two landmark Cold War-era national reconnaissance programs developed and operated film-return imagery satellites that provided United States (U.S.) national security leadership with invaluable foreign intelligence information and geodetic data. The five articles include diverse topics ranging from the geopolitical context of the period during which the National Reconnaissance Office (NRO) developed the programs; the Gambit and Hexagon systems' technical specifications that were ahead-of-their-time; the lessons learned by the contractor engineers from the challenges of program development; and, the intelligence value of the collected imagery that gave U.S. policymakers insight into Cold War threats and helped analysts advance the systemized photo-interpretation of space-based imagery. The authors have included examples of imagery and imagery-derived products derived from the film acquired by satellites from both programs. There are KH-9 mapping and panchromatic camera examples, and there are Gambit KH-7 and KH-8 examples. The Hexagon KH-9 panchromatic examples are from the first group of Hexagon panoramic camera images released to the public in January 2012. Additionally, the Gambit KH-8 reduced-in-quality examples in this publication are the only Gambit-3 image products that have been made publicly available at the printing of this publication in April 2012. The declassification efforts for the KH-8 and KH-9 imagery are ongoing and under the purview of the National Geospatial-Intelligence Agency. The various articles also include other photographs and figures that illustrate and enhance the stories.

In the programs' space reconnaissance missions that spanned three decades, Gambit (operational from 1963 to 1984) and Hexagon (operational from 1971 to 1984) collected a wealth of spaced-based intelligence that had a major impact on the national security policymaking of six American Presidents and played a significant role in reducing military and diplomatic tensions between the U.S. and the Union of Soviet Socialist Republics (U.S.S.R.). The NRO's investment in research, testing, and development of spacecraft, sensor payloads, film-recovery vehicles, and other system components helped advance space technology and laid the groundwork for innovations in other technical fields. In addition, the NRO derived management and engineering lessons that proved beneficial in developing successor satellite systems.

Gambit and Hexagon's capabilities dramatically advanced satellite state-of-the-art, and for years after operational missions for both systems effectively ended in 1984, all programmatic details—even program names—remained too sensitive to release publicly. More than a decade after first discussing the potential declassification of these legacy film-return systems, the veil has now been lifted.[1] In June 2011, the Director of the National Reconnaissance Office (DNRO), Bruce Carlson, officially declassified the programs. Three months later, he hosted a public announcement and display of select program

1 See "Looking Closer, Looking Broader: Gambit and Hexagon—The Peak of Film-Return Space Reconnaissance After Corona," p. 39, for a discussion of the declassification process.

artifacts on 17 September at the Udvar-Hazy Annex of the Smithsonian's National Air and Space Museum. With this event, the Gambit and Hexagon stories began to be told publicly.

The NRO took a second major step on 21 January 2012 to publicly tell the Gambit and Hexagon stories. On that date, DNRO Bruce Carlson joined the Director of the National Museum of the U.S. Air Force (NMUSAF), Lt Gen (Ret) Jack Hudson, in placing a full complement of Gambit and Hexagon artifacts on a long-term public display at the NMUSAF in Dayton, Ohio. This exhibit represents the largest collection of satellite reconnaissance artifacts ever assembled, declassified, and made public. It may be the largest display of intelligence capabilities ever made public. There are 28 major units of artifacts with numerous smaller components; end-to-end, and assembled, the artifacts would extend slightly more than the width of a football field; and together they weigh more than 42,000 pounds. Collectively (and with the earlier Corona program artifacts), they represent NRO's entire imagery capability for over one-half of the NRO's 50-year history.

This Gambit and Hexagon display at the NMUSAF can serve as a public resource to illustrate the various aspects of program hardware that the articles in this issue of the *Journal* address. At the same time, the articles in this special issue of the *Journal* can serve as a reference guide for those who view the displays.

In the first article, "Why Gambit and Hexagon: U.S. National Security and the Geopolitical Setting, 1957-1960," Dr. Susan D. Schultz explains why the U.S. Intelligence Community (IC) foresaw the need for a high-resolution satellite system and a broad-area-search and surveillance satellite system with capabilities beyond those expected of the then-in-development Corona photosatellite reconnaissance program. She underscores the IC's prescience in defining future satellite requirements and missions before Corona, which became the world's first imagery satellite, had even launched. For a brief period in the late 1950s, the U.S. appeared to be losing the space and arms race, which, given the U.S.'s then limited knowledge of Soviet capabilities and intentions, caused great concern in Washington and gave rise to fevered speculation in the American press. The Soviets were first to launch an intercontinental ballistic missile (ICBM), first to launch a satellite (Sputnik), and first to launch a spacecraft that reached another celestial body (the Luna 2, which impacted the moon), and these accomplishments convinced American national security leadership that their adversaries were developing a first-strike capability. From the mid-1960s to the mid-80s, Gambit and Hexagon would prove to be invaluable in providing intelligence on many threats, but Schultz explains that their primary *raison d'être* was to address the Soviet strategic threat already evident in 1960.

She begins her article with a discussion of the Satellite Intelligence Requirements Committee (SIRC), which in the summer of 1960 called for satellite systems with capabilities that addressed three urgent intelligence gaps: finding and surveilling Soviet ICBM launch sites; obtaining more detailed intelligence through higher-resolution spaced-based imagery; and providing greater technical specificity. These requirements, refined in subsequent years, formed the basis for the development of Gambit, the first high-resolution satellite imagery system, and Hexagon, the broad-area-search satellite system that replaced Corona. The SIRC was responding to multiple circumstances: the surprising rapidity of Soviet missile and space advances, for which history credits Sergei Korolev and his R-7 rocket; the military actions of the Soviet Union and China in the Middle East, Indochina, and Hungary; and the U.S.'s lack of hard intelligence data, made worse by the cessation of U-2 overflights after the 1 May 1960 shootdown of pilot Gary Powers. The influential Technological Capabilities Panel (TCP) report issued in February 1955 had given dire warnings of the Soviets' presumed ability to deliver a "fatal" first attack and concluded that Moscow had altered the strategic balance. Two years later, the "Gaither Report," a classified study leaked to the press, echoed the TCP, and urged U.S. leaders to obtain strategic warning and hard intelligence "even if some risks have to be taken." During this period, many articles appeared claiming the U.S. trailed in ICBM development and deployment, the so-called "missile gap."

How had the Soviets gained the technological upper hand? Schultz chronicles how early Soviet rocketry programs had advanced by 1937 to make the U.S.S.R. nearly equal to Germany, then the acknowledged world leader in rocket technology, when, abruptly, Stalin began a series of military purges that saw the execution or imprisonment of many top Soviet scientists. It was, therefore, all the more remarkable that the U.S.S.R. was able to recoup its early gains in rocketry—once Stalin accelerated research and development after the war—an accomplishment due in no small part to Sergei Korolev. In 1938, Korolev had been arrested, tortured, tried, and sentenced to 10 years hard labor, and he reportedly began conceptual work on ballistic missiles while imprisoned. After release he began work on shorter range missiles at Kapustin Yar. His ICBM work culminated with a successful R-7 launch, the world's first ICBM, on 21 August 1957, from a launch site called Tyuratam that the Central Intelligence Agency had only two weeks earlier photographed on a U-2 flight. Ironically, this more significant event caused less of a stir than the October 4 launch of Sputnik, the panicked reaction to which somewhat masked the genuine concern that President Eisenhower had over the lack of hard intelligence data on Soviet weapons and facilities. Eisenhower's authorization of U-2 flights, beginning on 4 July 1956, produced stunning photographs of missile bases and launch sites like Tyuratam, but often these images only served to foster a belief that the Soviets had many more such sites hidden in the vast spaces of the U.S.S.R. that had not been photographed. The resulting exaggerated intelligence estimates of Soviet capabilities made the search for deployed ICBMs a major priority in the late 1950s.

Schultz concludes that the Gambit and Hexagon missions, which addressed the ICBM threat by providing additional intelligence insight that Corona could not, were accordingly a direct response to the events of 1957–1960. It would be through these systems that the U.S. peered into Soviet strategic force development. Gambit high-resolution imagery, in particular the KH-8 camera system that began operations in July 1966, revealed the many challenges Moscow faced in following up its initial technological accomplishments. In truth, the Soviet missile programs, plagued by technical issues and a poor national economy, began to lag behind the U.S. by the early 1960s. At the same time, the U.S. successfully developed and launched Gambit-1, and began defining the technical requirements for what would become Gambit-3 and Hexagon. For more than a decade, these two systems operating in tandem provided the greater search and surveillance capability, and technical specificity on Soviet strategic forces and weapons, which the SIRC had defined as urgent intelligence needs in the summer of 1960.

In the second article, "Looking Closer and Looking Broader: Gambit and Hexagon—The Peak of Film-Return Space Reconnaissance After Corona," Patrick Widlake and I offer a concise but detailed introduction to the remarkable Gambit and Hexagon satellite systems that remained impressive for a quarter century after they ceased operations. We employ the metaphor of eyes in space, with which six U.S. Presidents observed the Soviet Union and monitored the strategic threat. Gambit and Hexagon—the former with its unusually high-quality imagery, the latter with broad-area coverage and superior resolution—together provided comprehensive photographic coverage through complementary surveillance and search missions, i.e., looking closer and looking broader. We analyze Gambit and Hexagon in two sections: the first summarizes the systems' technical details and capabilities, while the second summarizes the intelligence contributions that proved invaluable to a series of U.S. Presidents. We conclude that Gambit and Hexagon operations that were revolutionary by the standards of their time previewed what would become commonplace by the 21st century: satellite reconnaissance imagery routinely incorporated into intelligence and military operations; unclassified commercial space imagery available for purchase; and Internet sites like Google Earth where space imagery can be viewed anywhere in the world with a connected personal computer.

In the first section, we detail the technical specifications that enabled Gambit and Hexagon's extraordinary capabilities. Gambit-1 featured a Matsukov-type strip camera with an effective focal length more than three times the size of Corona. Its lens produced a larger image at the focal plane, providing substantial improvement in resolution. The KH-8 camera in Gambit-3 was even more advanced and could be operated in a number of different modes to produce stereo or monoscopic strips, and lateral pair or lateral triplet photography. The KH-8's ultimate resolution capability remains too sensitive to reveal at the time of this publication in 2012. The Hexagon KH-9 camera system featured twin, independently controllable, stereo panoramic cameras mounted side by side on rotating optical bars. As it photographed targets, the bars rotated 360 degrees continuously to photograph targets from 30 degrees through a maximum of 120 degrees of each scanning motion. The twin cameras could photograph a ground area 300 nautical miles (nm) wide by 16.8 nm long in a single frame. Hexagon carried huge film amounts, which the system returned in four recovery vehicles. The resulting system performed 2,000 imaging operations per mission, on average, and returned up to 60,000-plus frames of panoramic imagery. On 12 missions, Hexagon also featured a mapping camera subsystem (MCS) that contributed accurate ground coordinates for a wide variety of military, civilian, and intelligence programs.

In the second section, we summarize Gambit and Hexagon's national security and intelligence 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.

In assessing the Soviet strategic threat, the U.S. needed to monitor Moscow's ballistic missile development and deployment, and Gambit and Hexagon imagery—in conjunction with sigint assets—contributed much of the data that could be gathered without risking human life. Gambit's high-resolution imagery provided technical insight into the weapons' characteristics—essential for scientific and technical analysis—and Hexagon's panoramic imagery discovered new ICBM sites and monitored activity at known locations. Both systems provided visual "national technical means" for verifying compliance with arms control agreements. Hexagon's MCS photographed nearly all inhabited areas of the globe, contributing to the production of many small, medium, and large-scale maps and charts by the Defense Mapping Agency and U.S. Geological Survey. The MCS also proved well adapted to collecting large-acre crop inventory intelligence important in forecasting economic production of targeted adversary countries. Finally, multiple U.S. organizations, including the Department of Agriculture, Commerce, and Interior, and the Environmental Protection Agency used KH-9 MCS imagery for environmental monitoring, agricultural management, and disaster assessment. The latter usage presaged the more expansive support that NRO satellite imagery provides to disaster recovery in the 21st century.

In our article we conclude that Gambit and Hexagon left important legacies that influenced the development and subsequent operations of successor satellites, which in the 21st century ensure that the IC has access to a near-continual stream of imagery data for exploitation and analysis.

Next, there are two articles from former senior engineers with the Lockheed Missiles and Space Company, which developed the satellite control vehicle for the Gambit-3 program and the satellite basic assembly for the Hexagon program. Lockheed also served as the overall system integrating contractor for Hexagon. These articles serve to provide the inside story on the development of and improvements to the two satellites from Lockheed's perspective. They also highlight key lessons learned and implemented by the contractor program offices.

The first Lockheed article is from Pete Ragusa, a Chief Systems Engineer on the Gambit-3 program. In "Gambit-3: Engineering an Innovative High-Resolution Satellite—Program Management from the Lockheed Missile and Space Company's Perspective," Ragusa cites three pivotal systems engineering and program management innovations that made the Gambit-3 such a tremendous success. He explains that Gambit-3, the development for which began almost simultaneously with the commencement of Gambit-1 missions, was designed to improve upon the earlier system's capabilities and address reliability issues that plagued the first two years of Gambit-1 operations. Once the decision had been made to engineer an improved Gambit, Lockheed assembled a dedicated project team, following its practice on the Corona program.

The first key system engineering innovation on Gambit-3 was the implementation of a roll-joint on the satellite control vehicle, which addressed the problems Gambit-1 had experienced with its satellite control vehicle. The roll joint steered only the camera payload—not the entire spacecraft—to achieve more rapid maneuvers with minimal settling times and attitude control gas usage. Ragusa's second key innovation was the integration of a secondary propulsion system that increased the satellite's lifetime on orbit, which in turn allowed for the planning of more comprehensive missions and the taking of many more images. The most important innovation, Ragusa writes, was "adaptive bias," which integrated the roll joint, momentum compensation, an attitude control to improve the image motion compensation and yield very sharp, high-resolution images with better than two feet ground-resolved distance (GRD). Ragusa concludes that the Gambit-3 program succeeded because the program office embraced system engineering and management innovation.

The second Lockheed article is "Hexagon—'No Single Failure Shall Abort the Mission'—Managing System Integration for the NRO's Wide-Area Search Satellite from the Lockheed Missile and Space Company's Perspective," by NRO Pioneer Sam Araki and Steve Treat. Araki and Treat's central thesis is that Hexagon's challenging development succeeded because of a strong statement of need and total commitment from government and contractor management. They provide a first-hand perspective of Lockheed's role as system integrator, in which the company instituted rigorous program management practices that emphasized top-down system engineering processes and strong program controls to meet cost and schedule milestones without sacrificing performance. The authors emphasize how Lockheed implemented the lessons it had learned on the Corona and Gambit programs to develop its systems engineering approach. Key lessons contributed to the development of a factory-to-pad concept in which engineers performed system integration and testing at the factory to enable the shipping of a completely assembled, system-tested, and flight-ready satellite to the launch base. Araki and Treat credit the rigorous program management with contributing to the highly reliable Hexagon vehicle that never failed to accomplish the core intelligence and mapping missions because of an on-orbit anomaly.

The final article, Dr. Bruce Berkowitz's "The Soviet Target—Highlights in the Intelligence Value of Gambit and Hexagon, 1963-1984," discusses the important contributions these Cold War-era systems made to the U.S.'s diplomatic, military, and economic strategy of containing the Soviet Union. Berkowitz, the author of several books on intelligence and national security policy, describes how the systems were designed with different requirements sets in mind, but in practice Gambit and Hexagon's imagery populated common databases used by analysts to fill intelligence gaps and improve the IC's understanding of the Soviet Union. He acknowledges that the systems collected significant intelligence information on a range of high-value targets and a number of issues, but he also concedes that, ironically, for as much as they contributed to a body of intelligence knowledge, Gambit and Hexagon also created points of contention among intelligence professionals. Although Gambit and Hexagon improved the amount and quality of hard data available to analysts, their collection was nevertheless incomplete, subject to the inherent limitations of film-return satellite technology. Berkowitz concludes that Gambit and Hexagon's most important contribution may have been that the two programs made routine the integration of satellite imagery into the intelligence process and paved the way for the more advanced systems in place today.

To assess Gambit and Hexagon's intelligence impact, Berkowitz considers the extent to which each contributed to satisfying three major Cold War intelligence challenges: estimating Soviet strategic nuclear forces; monitoring Soviet compliance with strategic arms control agreements; and supporting deterrence policy. Both systems collected imagery on critical targets related to these challenges, with Gambit providing higher resolution surveillance to supplement, first Corona, then Hexagon collection, and Hexagon improving upon Corona's coverage capabilities with an even larger imaging swath area that allowed analysts to scan returned frames for a suspected target and then "zoom in" by magnifying the image to identify it.

Berkowitz compares Soviet strategic force estimating to assembling a puzzle without knowing what the final picture should look like and with only getting a few pieces at a time. During the 1960s and '70s, satellite imagery often provided the first indications of a new weapon being deployed by capturing a previously unobserved test system or support apparatus. Both Gambit and Hexagon made it possible for U.S. Intelligence to understand Soviet strategic weapons at a new level of detail, making it possible to develop weapons systems to counter them. Gambit's major contribution was to make it possible for analysts to identify, for example, what kinds of missiles the Soviets were about to deploy and the components used to assemble ballistic missile submarines. Hexagon's major contribution was its sheer collection volume that gave analysts the confidence that they had, or could get, imagery of Soviet sites, and that they had not missed a potential target of interest.

Berkowitz next assesses Gambit and Hexagon's role in monitoring Soviet compliance with strategic arms control agreements, which became a main pillar of U.S.–Soviet relations after the countries signed the Strategic Arms Limitation Treaty (SALT) and Anti-Ballistic Missile Systems (ABM) treaty. Hexagon's ability to provide visual verification was a significant justification for continuing its development after the Bureau of the Budget had temporarily cancelled the program in 1969. As Berkowitz discusses, both systems proved essential to verifying the dismantling or destruction of weapons prohibited by the SALT. For ABM treaty verification, the U.S. analyzed Hexagon and Gambit imagery to search for and determine whether suspected sites were ABM sites, in violation of agreed-upon limits.

Finally, Berkowitz credits Gambit and Hexagon's support to deterrence policy and military planning by noting how instrumental their data were for developing U.S. military force and operational plans. Gambit-3's high-resolution allowed analysts to distinguish between similar-looking weapons and vehicles and both systems contributed to the assembling of order of battle information and targeting data for U.S. strategic nuclear force use. Hexagon virtually revolutionized mapping, charting, and geodesy by scanning vast areas with an accuracy sufficient to meet military-grade map requirements.

This Gambit-Hexagon special issue of the *Journal* provides a broad overview of the programs' lasting contributions to U.S. national security and space technology. Collectively the articles help place the programs in the context of the Cold War and the NRO's 50-year history. These satellite reconnaissance programs represent outstanding examples of the Intelligence Community's (IC's) technological success and contributions to national security. They also demonstrate the benefits of strong and fruitful partnerships between intelligence agencies and with corporate counterparts in the industrial base-relationships that have so personified the NRO's way of doing business during its 50-year history.

Robert A. McDonald, Ph.D.
Editor

Why Gambit and Hexagon? *U.S. National Security and the Geopolitical Setting, 1957–1960*

Susan D. Schultz, Ph.D.

In the summer of 1960—one month before the first successful Corona launch—the U.S. government identified the need for higher resolution and broader area coverage as necessary follow-on national reconnaissance satellite programs: in July, the Satellite Intelligence Requirements Committee (SIRC) issued a report to the U.S. Intelligence Board calling for additional satellite systems with greater capabilities than planned for Corona.

Focusing on the impending Soviet strategic threat, the SIRC delineated three urgent intelligence gaps. The primary intelligence need was greater capability of *searching* for and *surveilling* Intercontinental Ballistic Missile (ICBM) launch sites in the Union of Soviet Socialist Republics (USSR). The secondary mission was to obtain more *detailed* intelligence on ICBM installations--i.e., imagery with greater resolution than Corona. Finally, imagery from the follow-on systems should provide *greater technical specificity* on the highest priority targets (Oder *et. al.*, 1991, p. 16).

Throughout the 1960s, 1970s, and into the 1980s, imagery from the systems (Gambit, 1963–1984; Hexagon 1971-1984) were to prove invaluable against many other threats from around the world, as well as provide valuable intelligence beyond adversaries' strategic capabilities;[1] but the primary *raison d'être* for the systems was to address the immediate Soviet threat in the summer of 1960. For it appeared at this juncture that undeniably the Soviets might be developing a first-strike capability. It appeared that the U.S. was indeed in severe danger of a surprise attack.

By 1960, the Soviets appeared to be far ahead of the U.S. in what was emerging as an arms and space race, a feat that had been possible only because of Sergei Korolev's R-7 rocket: Moscow had launched the world's first ICBM in the summer of 1957 and two months later, the world's first satellite *(Sputnik).* In 1959, they had successfully launched *Luna 2,* impacting the moon and thus becoming the first spacecraft to reach another celestial body.

By 1960, the U.S. had little or no intelligence on the impending Soviet threat. Subsequently, Corona was able to dispel the so-called "missile gap." While Corona enabled the "counting" of the missiles and missile sites, it lacked the resolution needed

1 See McDonald and Widlake, "**Looking Closer and Looking Broader:** *Gambit and Hexagon–The Peak of Film-Return Space Reconnaissance After Corona.*"

to gain greater insight into the Soviet strategic weapons program. It was to be the higher resolution Gambit satellites, particularly with the KH-8 beginning in 1966, and the surveillance capabilities of Hexagon in conjunction with Sigint platforms that the U.S. finally gained critical knowledge on Soviet strategic systems. Only via these systems would the U.S. "peer" into Soviet strategic force development.

How is it that in the summer of 1960, even a month before the first successful Corona launch, the U.S. Intelligence Community (IC) had the foresight to define so accurately the need for these two systems? What was the IC responding to, and what did it hope to achieve with these two systems?

It is only within the context of the 1957–1960 U.S. national security and geopolitical environment that the question of "Why Gambit and Hexagon?" can be fully answered. Accordingly:

- What was the state of the Cold War by 1957 and how is it that the Soviet Union—despite a poor economy—was able to achieve so many "firsts" and technological advancements in rocketry?
- How did the U.S. react to the Soviet "firsts" and what did the U.S. Intelligence Community (IC) specifically know in 1960?
- What really was the Soviet strategic capability by 1960 and how did Gambit and Hexagon provide the insight needed, explaining what Corona could not?

Indeed, an examination of the 1957–1960 context only highlights the foresight of the IC in envisioning these two systems—systems that would go on in the next two decades to not only fulfill their original missions, but also go beyond, and do so with stunning success.

1957: The Immediate Need for Intelligence Against the Threat

On 5 August 1957, a Central Intelligence Agency (CIA) U-2 overflight detected and took the first photograph of what appeared to be a CIA-suspected missile launch site in Kazakhstan—subsequently termed Tyuratam.[2] Reportedly, however, CIA photointerpreters were still analyzing the imagery from the flight when two weeks later, on 21 August 1957, the Soviet Union—after several failed efforts—from the same site launched the world's first Intercontinental Ballistic Missile (ICBM): an R-7 ("Semyorka" or "Little Seven"), whose dummy warhead impacted the Pacific Ocean about 6,400 km downrange. The Soviets then conducted a second successful test several weeks later—on 7 September.

Before the initial imagery from the U-2 flight confirming the existence of Tyuratam could even be developed, the Soviets proceeded with a related technological breakthrough—successfully launching the world's first artificial satellite from Tyuratam on 4 October 1957.[3]

In the wake of the Soviet's successful launch of the world's first ICBM and *Sputnik* in 1957, the President's Board of Consultants on Foreign Intelligence Activities (PBCFIA) issued a report to President Eisenhower recommending an evaluation of overhead reconnaissance systems, to include satellites. In a series of daring efforts between June of 1959 and Corona's first successful launch in August of 1960, U.S. intelligence officers, scientists,

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2 By 1957, the CIA had begun to suspect the existence of a long-range missile launch site near the Aral Sea. In May 1957, President Eisenhower approved U-2 overflights dedicated to locating missile and nuclear facilities, and specifically finding the suspected long-range missile launch site. When a U-2 pilot finally snapped the first photograph on 5 August—which he had found by flying along the rail-lines in the area—the U.S. had no name for the launch site. As CIA photointerpreter Dino Brugioni prepared to brief President Eisenhower on this initial image, he examined maps in an effort to find a place name. One map—made by the Germans in WWII—indicated a small community in the vicinity of the facility—"Tyuratam," which means "arrow burial ground" in Kazakh (Pedlow, pp. 135-36).

This site, a railroad station, had been chosen by the Soviets as early as 1955 as a long-range ballistic missile launch site precisely because of its isolated location—a sparsely settled region in the Kazakhstani desert about 200 kilometers east of the Aral sea, and far removed from the shorter range missile site at Kapustin Yar, which was more vulnerable to Western espionage collection. On their part, the Soviets have always termed the missile site "Baikonur," even though the town of Baikonur is 400 kilometers from the missile launchpads.

Terming "Tyuratam" "Baikonur" in international fora was actually a Soviet counter-deception effort to keep the long-range missile site a secret. Explaining the choice of nomenclature five decades later, Alexander Alexandrovich Maximov—Head of Space Forces of the Soviet Ministry of Defense at the time—explained that because of an existing international treaty, Moscow had to register the 21 August 1957 ICBM launch with the United Nations, indicating the date, time, and *place* of launch. He explained that Moscow was "not keen to divulge that information for security reasons." So intentionally Moscow decided to give the TASS news agency and the United Nations the name of a place hundreds of kilometers *away* from Tyuratam: Baikonur. (See Maximov's recollections, in Rhea, p. 328)

In subsequent years, the Soviets significantly expanded the Baikonur Cosmodrome; it became the primary Soviet launch center for not only long-range missiles, but also satellite and manned-spaceflight programs. Its multiple launch capabilities were included as critical inspection sites under the Strategic Arms Reduction Treaties (START) treaties.

3 Other Soviet "firsts" in space history followed shortly thereafter from precisely the same Tyuratam launch site #1, and all with Sergei Korolev's R-7 launch vehicle. On 12 September 1959, the Soviets successfully launched *Luna 2*, impacting the moon and thus becoming the first spacecraft to reach another celestial body. Similarly, *Luna 3*, launched from Tyuratam on 4 October 1959, swung around the moon and, with the sun behind it, took the first photographs of the far side of the moon. The film was developed automatically onboard, scanned by a television unit, and transmitted by radio to the ground (Harford, p. 143ff). And finally in 1961, from the same launchpad the Soviets launched the world's first manned spacecraft, Vostok-1 with cosmonaut Yuri Gagarin.

and rocket engineers, working with a sense of urgency, quickly mounted a focused effort to launch the world's first photoreconnaissance satellite into space (McDonald, p. 40ff).

The pressing U.S. national security need to gain more hard intelligence on Soviet strategic capabilities had become even more urgent in May of 1960 after U-2 pilot Francis Gary Powers was shot down four and one-half hours into his flight by an SA-2 surface-to-air missile, thus ending U-2 overflights. Ironically, his primary targets had been the Tyuratam Missile Test Range, the military-industrial sites near Sverdlovsk, and Plesetsk—600 miles north of Moscow, and a critical site where U.S. intelligence officers suspected Moscow was deploying the first *operational* ICBMs. Indeed, "Operation Grand Slam" was the most daring of all U-2 flights, since it was intended to cover so much of the Soviet Union. Moreover, the timing of the flight was critical: if these key sites were not photographed between May and July, the sun's angle would preclude further imagery for another year (Pedlow, 1992, p. 172 ff).

Moscow vigorously protested and publicized the incident; President Eisenhower had no choice but to cancel overflights. Thus it was that by the summer of 1960, the U.S. had little or no hard intelligence on the perceived looming Soviet advantage in strategic weapons. Analysts at CIA suspected that Moscow might be deploying ICBMs at Plesetsk and Tyuratam, which is why Gary Powers' U-2 flight mission had been so important. And Corona's ultimate success was still uncertain. Finally, throughout the U.S. government there was an intense awareness that, even if Corona were successful, additional satellite systems with greater capability were acutely needed.

Thus did the U.S. arrive inescapably to the conclusion that Corona follow-on systems were urgently needed: Gambit and Hexagon.

1957: The State of the Cold War

> *"I am certain that we shall quite soon have a ballistic missile with a hydrogen bomb that can fall anywhere in the world."*
>
> —Soviet Premier Nikita Khrushchev, as quoted by *Time*, "Foreign News: Fist for a Fist," 7 May 1956

> *"The next war will be 'fought on the American continent, which can be reached by our rockets....' "*
>
> —Soviet Premier Nikita Khrushchev as quoted by *Time*, "The Nation: Missiles for NATO," 25 November 1957

The 1950s were by and large characterized by periods of increased attempts at *rapprochement* between Washington and Moscow and periods of increasing tension.[4] Ironically the progress made towards *rapprochement*—namely the Geneva summit talks aimed towards reducing the impending arms race—faltered precisely due to the very thing Gambit and Hexagon imagery would ultimately provide, namely verification of the Soviet strategic capability. And without verification and the ability to reach an arms control agreement, unresolved tensions from the end of the 1940s would harden into a Cold War stalemate, exacerbated by the development of long-range delivery systems for nuclear weapons, Soviet Premier Nikita Khrushchev's braggadocio, and fears in the West in lieu of hard intelligence.[5]

In 1945 there had been nothing per se to presage that inevitably the next four and one-half decades would harden into a 20th century Cold War stalemate between the U.S. and the Soviet Union, with periods oscillating between tones of aggression followed by overtures toward détente.[6] However, a series of developments in the late 1940s and early 1950s set the pattern that would emerge: efforts were made for summits geared towards reaching peaceful resolution of conflicts; simultaneously, however, actions on the ground would often escalate tensions and preclude progress at summits. Many conflicts were left unresolved and would continue to erupt during the next four decades. For example, the contentious "German Question" was never really resolved: what had looked like a reasonable solution in 1945—that the four conquering Allies would occupy zones of the

4 Needless to say, the secondary literature on the Cold War is extensive and extends beyond the scope of this analytic essay. For a listing of major works, see the Carnegie Mellon University's Cold War Science and Technology website at http://www.cmu.ed21st centuru/coldwar/annot.htm; the Cold War Studies project at Harvard University at http://www.fas.harvard.edu/-hpcws/index2.htm; and the Cold War International History Project, the Woodrow Wilson International Center for Scholars in Washington, D.C., at http://cwihp.si.edu/default.httm. Though somewhat dated, for overviews also see: John Lewis Gaddis, Long Peace: Inquiries into the History of the Cold War; "The New Cold War History" (1998) at http://www.unc.edu/depts/diplomat/AD_Issues/amdipl_9/gaddis_coldwar.html, and, more recently, Gaddis, The Cold War: A New History, 2005. Also, see the review by Michael Beschloss, "Look Back in Relief," The New York Times (15 January 2006).

5 An early Cold War history, written by D.F. Flemming, first published in 1961, describes the 1955–59 period as "The Second Cold War," based on the failure of the July 1955-October 1956 initial arms control meetings in Geneva. Even more interesting is Flemming's two volume history as a historical document. Writing in 1961, one of his concluding chapters is amazingly entitled "Why the West Lost the Cold War." See Flemming's *The Cold War and Its Origins.*

6 There is a significant body of literature on the origins of the Cold War, as well as what has been an extremely emotional debate as to which side has been more culpable in starting and escalating the Cold War. For an overview of this often acrimonious debate among historians, see J. Samuel Walker, "Historians and Cold War Origins: The New Consensus," in Gerald K. Haines and J. Samuel Walker, Editors, *American Foreign Relations: A Historiographical Review,* pp. 207-36.

Put succinctly, historians in the debate usually fall within one of several categories. Those of the *orthodox* school —the prevailing consensus in Cold War literature of the 1950s and early 1960s—blamed the Soviet Union for the Cold War, arguing that the U.S. had no choice but to contain and where possible to reverse the expansion of an aggressive Communist state dedicated to overthrowing Western capitalism and democracy. By the end of the 1960s, however, a growing body of scholars (principally Walter LaFeber, Lloyd C. Gardner, Barton J. Bernstein, Stephen E. Ambrose, and Joyce and Gabriel Kolko) were publishing major studies questioning this interpretation. These adherents of the *revisionist* school blame the U.S., arguing that the U.S. was determined to expand capitalism by securing unlimited access to the world's markets and resources, aggressively attempting to crush all revolutionary movements in order to accomplish its expansionism. Finally, adherents of the *post-revisionist* school blame both the U.S. and the USSR, arguing that both sides took actions that provoked hostile reactions entailing an unending "action-reaction" cycle. J. Samuel Walker indeed argues that by the late 1970s—after extensive research and debate—traditional and revisionist interpretations have produced a "new cold war consensus"—both the U.S. and Russia shared responsibility for the onset of the Cold War in approximately equal proportions.

former Reich, to include a four-power occupation of its capitol Berlin—by 1960 had led to the formation of two separate states on the frontlines of the Cold War divide. Other unresolved tensions from the period would likewise feed into the eventual Cold War stalemate: for example, in 1948 the Communists achieved a coup in Czechoslovakia; China fell in 1949 to Mao's Communists with the subsequent Sino-Soviet Bloc between Moscow and Beijing; and the early 1950s saw North Korean aggression (aided by China) in Korea.

However, with Stalin's death in 1953 there appeared—at least for several years—a resolve on each side to lessen tensions. The collective leadership after Stalin was convinced that their major priority needed to be improving the poor economic conditions and outlook of the Soviet Union; relaxing tensions with the West was viewed as being an important component of their need to shore up the failing Soviet economy. Soviet Premier Georgi Malenkow reportedly even looked favorably on summit talks to resolve the German Question. Meanwhile, President Eisenhower and his foreign policy team were convinced that peaceful co-existence was a real possibility but the U.S. must ultimately be "ahead" in the Cold War and counter perceived Soviet aggression; however, not unlike their Soviet counterparts, the Eisenhower Administration, too, was deeply concerned by the costs of national security programs and the large U.S. national debt[7] (Leffler, p. 89ff).

Thus, by the end of 1953 the Eisenhower Administration had reached a policy of deterrence, containment, and prudent rollback, i.e., that the U.S. possess the capability of inflicting massive retaliatory damage through offensive capability while pursuing arms control—all designed to prevent Soviet aggression. Nuclear deterrence and massive retaliation would enable the U.S. to cut the budget, saving money on conventional forces.

The Korean War had a major impact on the Eisenhower Administration and was to have a major influence upon policymakers' formulation of a military strategy towards the Soviet Union during the 1950s. The unexpected aggression on the part of the Communists in Korea induced Eisenhower to believe increasingly that nuclear deterrence had to serve as a fundamental foundation of U.S. strategy. The deterrent strategy was first publicized in a speech by Secretary of State John Foster Dulles on 12 January 1954. Nuclear deterrence—and the threat of massive retaliation—would prevent war.[8]

Also in January, 1954, for the first time in five years, U.S., French, British, and Soviet foreign ministers met in Berlin in an effort to hammer out an acceptable resolution to the German Question. The U.S. position was firm—free elections in all of Germany as a prelude to German unification, with the Soviets disagreeing. All parties, however, agreed to hold another conference, this time in Geneva, and deal with an entire host of issues to include Korea, Indochina, and arms control.

7 Somewhat ironic from today's vantage point, when Eisenhower learned at a July 1953 National Security Council meeting that the U.S. national debt was about to exceed eight billion dollars and that the U.S. Congress would have to raise the debt ceiling, he reportedly remarked: "We are in a hell of a fix" (Leffler, p. 125).

8 There are many excellent secondary sources on the Eisenhower Administration's national security strategy. I recommend beginning with the selected bibliography on the website of the Dwight D. Eisenhower Presidential Library and Museum at http://eisenhower.archives.gov/Research/Bibliography/Bibliography.html.

The July 1955 Geneva summit with the "Big Four" was intended to begin long-term negotiations on a broad range of contentious issues, to include trade agreements, the emerging arms race, and possible disarmament treaties; it is here that President Eisenhower proposed an "Open Skies" plan, calling for an international aerial monitoring system.[9] President Eisenhower's "Open Skies" initiative was an effort to avert the possibility of a surprise attack by either side—an initiative that Moscow eventually rejected, claiming that U.S. overflights by reconnaissance aircraft could be used for extensive spying.

In a remarkable quirk of fate, Nikita Khrushchev attended the 1955 meeting, and came away with a predominant lingering belief that Moscow had been humiliated at the Geneva meeting—primarily due to the qualitative difference between U.S. and Soviet aircraft capabilities. Western delegations arrived on four-engine planes, but the Soviets on two-engine planes. His son, Sergei Khrushchev, claimed that until he died his father never forgot his humiliation from this fact (Taubman, W., p. 350ff).

As both sides continued to develop, test, and stockpile nuclear weapons during the 1950s, both Moscow and Washington gradually reached agreement that some sort of international limitations on nuclear testing were needed. However, a series of talks and initiatives were plagued by the question of verification—with verification becoming ultimately the stumbling block to a comprehensive ban on testing. The West was determined to ensure that an international agreement on nuclear testing would not be vulnerable to clandestine violation; however, the U.S. lacked the means of verification. On their part, the Soviets insisted that formal verification measures were not necessary—and therefore Soviet territory did not need to be inspected.[10]

Meanwhile, these initial arms control talks were not transpiring in a vacuum. Several key developments and events in 1956 heightened public apprehension and prompted an increasing skepticism about the fruitfulness of the Geneva negotiations: the long-simmering tensions in the Middle East in the Suez Crisis; increasing Cold War conflicts in the Third World to include Indochina; and the November 1956 Soviet invasion of Hungary.

Even before the Soviet occupation of Hungary, U.S. distrust of the Communist world was growing, due to these various Third World skirmishes. By March of 1956, an escalating number of the most respected pundits in U.S. journalism were in unison in lamenting what they perceived to be a lack of U.S. policy in *deterring* Soviet expansionist ambitions: *The New York Times* reporter James Reston noted that the Communist political and economic offensive in the Middle East and South Asia was invoking the "greatest apprehension since the Korean War," and suggested that the U.S. might be losing "the

9 On the 1955 Geneva summit, see Gunter Bischof, *Cold War Respite: The Geneva Summit of 1955.*

10 President Harry S. Truman had established the Science Advisory Committee in 1951 in the Department of Defense. In response to the Soviet 1957 ICBM and *Sputnik* launches, President Eisenhower upgraded the committee and moved it to the White House in November of 1957. For an overview of the role of scientists, see Zuoyue Wang, *In Sputnik's Shadow: The President's Advisory Committee and Cold War America.* For a treatment of scientists and the role in the need for verification in arms negotiations, see James Killian's *Sputnik, Scientists, and Eisenhower and Benjamin P. Greene, Eisenhower, Science Advice, and the Nuclear Test-Ban Debate, 1945-1963.*

initiative in the world struggle with the Communists"; pundit Walter Lippmann claimed that in the past six months "we have suffered the biggest setback since the Communist victory in China"; and Joseph and Stewart Alsop opined that after the 20th Congress of the Soviet Communist Party,[11] the Soviet rulers were confident and "sure that the tide of history is now flowing ever more rapidly in the direction of the world hegemony they seek" (*Time,* 1956a).

This apprehension about Soviet intentions and capabilities only escalated in October and November when Moscow sent over 150,000 troops and 2,500 tanks into Hungary to quell what had become a spontaneous resistance to Soviet-imposed policies. Echoing widespread reaction in the West, *Time* editors ominously noted: "The belief in Soviet good intentions [i.e., the thaw in the wake of Stalin's death in 1953]...has been grievously shaken" (*Time,* 1956b).

By a year and half later, the voices criticizing U.S. policy would reach a new fevered pitch when the Soviets launched the world's first ICBM, followed shortly by the world's first satellite. To most Americans, it appeared the U.S. and West were indeed "losing" the Cold War.

1957: A Paradigmatic Shift in 20th Century Warfare—Nuclear Strategic Bombers and the ICBM

> *"The ICBM is the nearest thing to an 'ultimate weapon,' complete with delivery system, that has ever been conceived..."*
>
> —*Time*, 30 January 1956, "Science: Missiles Away"

> *"Production of rockets is now a matter of mass delivery—like sausages that come out of an automatic machine."*
>
> —Soviet Premier Nikita Khrushchev to the UN General Assembly, October, 1960 (As quoted in *Time*, 24 October 1960, "United Nations: The Thunderer Departs")

The Soviet 1957 "firsts" with the ICBM and *Sputnik* shocked the American public. How is it that the Soviets had achieved such technological feats? Certainly the U.S. public had been alarmed by the earlier unexpected Soviet ability to develop both the atomic and hydrogen bombs. But the lethality of these bombs and their ability to induce fear were directly proportional to the ability of man to invent suitable long-range delivery systems. By the end of the 1950s, with strategic nuclear bombers and Intercontinental Ballistic

11 It was also at the 20th Congress of the Communist Party of the Soviet Union in February 1956 that Nikita Khrushchev gave his "Secret Speech" denouncing the personality cult and dictatorship of Joseph Stalin. However, only parts of the "Secret Speech" were publicized in 1956, with the full speech not published until as late as 1989. So at the time journalists like the Alsops had a particularly negative reaction to the 20th Congress and what they believed was now irrefutable proof of Soviet expansionist intentions. Basing their assessment on observations from U.S. diplomats and Soviet experts (such as Ambassador Charles E. Bohlen), the Alsops were struck by the "remarkable" self-confidence of party leaders at the Twentieth Congress. See "U.S. Miscalculates Communist Strategy," 5 March 1956 in *Time.*

Missiles (ICBMs), both sides had developed this capability. However, by the mid-1950s Moscow—due to geography and its difficulties in developing strategic bombers—began to accelerate its development of the ICBM, with an ambitious goal of actually *deploying* numerous operational ICBMs throughout the Soviet Union.

Of the two long-range delivery vehicles, in certain senses the ICBM was the more formidable weapon. It required no pilot. From a continent away, and within eventually only 30 minutes, each side could deliver a lethal thermonuclear warhead to the adversary's territory. And it was ultimately the Soviet threat in this area—its real achievements in ICBM development as well as related "firsts" in space between 1957 and 1960—that escalated the fears in the U.S. For the first time in nearly 200 years, the vast Atlantic and Pacific Oceans could no longer protect the U.S. mainland.

To put it in perspective: the 9-megaton warhead--the size of the weapon on the U.S. ICBM strategic missile systems in the early 1960s—detonated at the Washington Monument would more or less level Washington, D.C. out to the Beltway in every direction, a distance of 15 miles (Graham, p. 15). In a matter of 30 minutes, a Soviet ICBM could strike Washington, D.C., and the U.S. President and national security apparatus had only *20 minutes* to decide whether to launch strategic nuclear missiles before the detected Soviet missiles arrived.

To some degree, only gradually during the 1950s did the U.S. lose its smug sense of technological superiority as the Cold War heated up in the 1950s. After all, the U.S. had a far superior economy, and the average U.S. citizen's standard of living was extremely impressive when compared to that of his Soviet counterpart. Moreover, the U.S. had been first in developing nuclear weapons. Thus, the U.S. had been caught by surprise when the Soviets announced their first successful detonation of an atomic bomb in 1949.

By the mid 1950s, it appeared to the West that the Soviets had developed a large force of strategic bombers able to deliver nuclear weapons across the Pacific and Atlantic Oceans. Soviet intercontinental bombers first appeared in the July 1955 Moscow air show. The bombers flew in "waves," giving the West the impression that Moscow had more bombers than they had anticipated; in point of fact, there were only a few bombers that circled around, although the U.S. had no means of knowing this in 1955. Thus, between 1955 and 1957, the U.S. Air Force estimated the Soviets had as many as 700 or 800 strategic bombers.[12] A year later, in testimony before the U.S. Congressional Air Force Subcommittee of the Senate Committee on Armed Forces, General Curtis LeMay was predicting that by 1960 the Soviet Union would have substantially more Bisons and Bears than the U.S. would (Sheehan, p. 151). However, U-2 aerial reconnaissance flights had by 1958 effectively dispelled the so-called "bomber gap," with U.S. intelligence analysts able to definitively verify that the Soviets never deployed more than 150, and not the 700-800 estimated by the Air Force (Pedlow, p. 111ff).

12 The literature on the so-called "bomber gap" in the 1950s is quite extensive. The reader is advised to begin with the CIA's Center for the Study of Intelligence (CSI) collection of NIEs with commentary in *Intentions and Capabilities,* edited by Donald P. Steury, p. 5 ff. and collection of essays, *Watching the Bear,* at CSI's unclassified website.

Even more significantly, aside from the U.S. overestimation in the number of Soviet heavy bombers, the bombers never actually presented an immediate threat of a surprise attack. This was because of the fact that U.S. analysts erroneously believed the Soviets were farther along in developing an intercontinental capability of aerially refueling the bombers—which in point of fact even by 1959 the Soviet Air Force had not developed. Without a refueling capability, Soviet bombers could fly only one-way intercontinental missions to the U.S. Moreover, the strategic bombers were based deep within the Soviet Union, and would have had to be staged forward before flying to the U.S. Clearly, doing this would give away the Soviet intentions and make them vulnerable to U.S. preemptive strikes.[13] Khrushchev himself played a critical role in Moscow's decision to step back from relying on the heavy bomber (Khrushchev, p. 455ff, and p. 469).

All in all, Moscow's increased focus on the ICBM was directly a result of the fact that its strategic bombers were unable to serve as an effective long-range nuclear delivery vehicle. Unlike the U.S., the Soviets could not deploy its bombers near the adversary's borders and would have no capability of strategic surprise. In contrast, by the mid-1950s, the U.S. strategic forces included more than 1,200 bombers capable of delivering about 2,000 weapons to targets in Soviet territory. Even as late as 1962, the Soviets had only about 160 bombers capable of delivering about 270 nuclear weapons to U.S. territory (Podvig, 2001, p. 4).

Thus, the Soviets felt compelled to quickly develop the ICBM as their primary intercontinental delivery vehicle for nuclear weapons. And it is truly to Stalin's credit that beginning in 1945, despite a military and economy in shambles,[14] he rapidly began to allocate resources to nuclear devices and long-range delivery systems, an initiative that would result in the Soviet advantage in long-range missiles in surprising breakthroughs between 1957 and 1960. As one expert has astutely noted, "Of all Stalin's imprints on Soviet and world history, the technological is perhaps the least appreciated..." (McDougall, pp. 41-41).

Clearly, as conquering powers in 1945, the Soviet Union, the U.S., and Great Britain all profited from the advanced technological know-how of the Germans at the end of World War II, augmenting their own indigenous missile development with the advances Hitler had been making on the V-1 and V-2. However, Moscow had several serious disadvantages. After having fought for over four long years on Hitler's "Eastern Front" in some of the most brutally bitter battles in the European theater, Stalin's military was utterly depleted and the Soviet economy was in shambles.

Secondly, however, the U.S. and Great Britain were better positioned to gain an advantage in acquiring the Third Reich's technological know-how, since they were first to occupy the province of Thuringia, where the main V-2 manufacturing plants were located. Thuringia, as part of the Yalta Agreement, was eventually to become a Soviet zone of occupation; forced thus to pull out, the British and the Americans seized and took with

13 *Ibid.*
14 For a treatment of the poor state of Soviet capabilities in 1946, see Harford, p. 93ff.

them practically all the V-2 equipment, to include missiles, control systems, components and ground equipment (Rhea, p. 102). Moreover, through "Operation Paperclip," the U.S.—before departing the Soviet zone—ensured that the West "processed" into its zone some 150 leading German V-2 scientists and rocket experts.[15]

Thirdly, however—in an irony of history—it had been Josef Stalin himself who had contributed senselessly to creating the pitifully weak state of the Soviet military rocketry in 1945 (Harford, p. 91). Beginning in 1936, in a fit of inexplicable rage and probably induced by his tendency towards paranoia, Stalin had begun a series of political repressions, involving a purge of Communist Party and government officials, the *kulaks,* and the Red Army leadership.[16] He thereby practically destroyed what had been an extremely innovative Soviet rocket program.

During the 1930s, Soviet work on rockets and efforts to achieve space flight had actually been quite advanced. Indeed, as one historian has accurately noted, until 1937 Soviet rocketry was "almost on par with that in Germany, which in turn was far ahead of that anywhere in the rest of the world, including the United States" (Stine, p. 125). In the 1930s, Sergei Korolev worked for the powerful Soviet Armaments Minister Mikhail N. Tukhachevskiy, the highest ranking Soviet military officer in the Red Army. Tukhachevskiy was intrigued by the possibility of rocket weapons and enthusiastic about the idea of space travel. He procured funding and rocket research flourished: in 1933 the first free flight of a Soviet-made liquid-fuel rocket took place at an army base near Nakhabino, outside of Moscow (Ober, p. 18; Harford, p. 29ff).

By 1937, however, these innovative nascent rocket research efforts were abruptly terminated when Stalin began to arrest Red Army leaders. His ostensible justification was a series of purported correspondence between Marshal Tukhachevskiy and the German high command. Tukhachevskiy was taken prisoner, interrogated, tortured and finally "confessed" that he was actually a German agent. After a "show" trial, he was summarily shot in the head in 1937.

Similarly, many other leading rocket scientists and military officers were arrested and interrogated, tortured into "confessing" lack of loyalty to Stalin, summarily shot or imprisoned, often in the *Gulag.* Sergei Korolev was arrested in June 1938, and charged with misusing rocket research funds. After being tortured in the Lubyanka prison, he was "tried" and sentenced to 10 years of hard labor. After a brief stay in a transit camp, he was sent to a labor camp in the harsh Kolyma region in Northeast Siberia. Conditions were brutal—freezing temperatures, lack of food, lack of basic hygiene, excessively hard labor, and brutal treatment by guards meant that not many inmates survived the harsh conditions in the brutal Siberian camps.[17]

15 "Operation Paperclip" was an Office of Strategic Service (OSS) program in 1945 to recruit Hitler's top scientists. For accounts of this operation, see: Linda Hunt, *Secret Agenda;* Burghard Ciesla *et.al., Technology Transfer Out of Germany After 1945;* and Clarence Lasby, *Project Paperclip.*

16 It was the historian Robert Conquest who first treated the era in fuller detail in his 1968 history entitled *The Great Terror.* He intentionally chose the phrase "terror," based on the "Reign of Terror" during the French Revolution.

17 For a well-done comprehensive treatment of Korolev, see James Harford, *Korolev.*

In 1939, Korolev was transferred from Kolyma, re-tried, and transferred to a *Sharashka.* Sharashkas were special prisons for intellectuals and the educated. Andrei Tupolev, the airplane and strategic bomber designer, was searching for rocket experts, and reportedly had requested him. Apparently, it was during this period of incarceration in a Kazan Sharashka that Korolev began to work on the ballistic missile concept. In June of 1944 he—along with Tupolev and the rocket scientist Valentin Glushko[18] —was formally discharged by a government decree, although the charges against him were not dropped until 1957 (Harford, p. 97ff; Gruntman, p. 273ff).

By 1945, however, with the beginning of the first rumblings of the Cold War, Stalin made up for his prior mistakes and rapidly took the offensive in accelerating the Soviet Union's ability not only to develop both the atomic and hydrogen bombs in rapid succession, but also to re-coup the gains that had been made on rockets in the 1930s. As early as 13 May 1946, the Council of Ministers of the USSR dedicated a meeting to the "matters of the rocket weapons," establishing the basic organizational structure for an indigenous development of these weapons based on the German V-2. Soviet engineers and rocket scientists were sent to Germany and charged with returning with any material they could seize. The decree also called for the establishment of a test center and design bureaus and ordered that 500 specialists be selected for rocket work (Gruntman, p. 275ff).

A year later, in 1947, Moscow established the first large-scale missile test range, the "State Central Rocket Testing Range N. 4" near the town of Kapustin Yar on the eastern bank of the Volga River, 70 miles southeast from Stalingrad. Until the establishment of Tyuratam in the 1950s, Kapustin Yar was to be the main center for Soviet missile testing. It was here that Korolev was sent and from where he spearheaded much of the initial work on cruise missiles and shorter range—with an eye towards longer range—rockets.

From the outset, however, Stalin's primary goal was that the Soviet Union develop the long-range missile. In 1947, at a Communist Party Politburo meeting he stressed that priority should be given to "rocketry" and that the Soviet Union needed to develop "transatlantic missiles." No limits should be placed on the funding available to achieve that goal (Rhea, p. 287). On 14 April 1947 Stalin summoned Korolev to a key meeting of a special commission that called for the development of a long-range plan for rocket technology development. The group consensus was that German V-2 technology was past its prime—a new approach was needed for the development of an ICBM (Harford, p. 97).

18 Valentin Glushko, a Soviet engineer, was the principal Soviet "Chief Designer" of spacecraft and rockets during the Cold War. See Mike Gruntman, *Blazing the Trail.*

Korolev began work at Kapustin Yar[19] for what would eventually become the "R" series in Intermediate Range Ballistic Missiles (IRBMs). [See Table 1.]

With Stalin's death in March of 1953, the Soviet government reexamined the strategic weapons program. On 12 August 1953 the Soviets successfully tested a hydrogen bomb, only 10 months after the U.S. had detonated a 10.4 megaton bomb. Shortly thereafter, at the Presidium at the Council of Ministers, a decision was made to upgrade Andrei Sakharov's bomb to a 1-2 megaton yield and attach it to a huge intercontinental missile. It was at this meeting that Korolev played a key role.

As indicated, Korolev had been working on missiles at Kapustin Yar, particularly the intermediate range R-3. According to several accounts from those at meetings, Korolev shocked everyone by suggesting that the R-3 program be cancelled, arguing that the missile had only a 3,000 km range and therefore was not what was needed. He believed what the Soviet Union really needed was an ICBM with a range of 7,000 to 8,000 km, with a range capable of hitting the continental U.S. (Zaloga, 1993, p. 135ff).

At a 30 May 1954 follow-on meeting, Korolev promised to have the R-7 long-range missile ready by 1957. By fall of 1954, he had completed a preliminary design (Zubok, p. 124). And in 1954, according to Vladimir Pavolvich Barmin, Director General of the General Machine Building Design Bureau, work began on R-7 missile ground support equipment (Rhea, p. 37).

Next, a new long-range missile launch site was needed. Kapustin Yar was too small for long-range extensive missile work and testing. Moreover, its location near population centers was a disadvantage, both in terms of potential casualties but also due to the need to protect the highly secretive work on strategic ballistic long-range missiles. A special commission composed of both military and civilian experts was tasked to find an ideal site. The commission ended up with three possibilities: Makhachkala in Dagestan on the Caspian Sea; the forested region of the Mordovian Republic; and a site near the Tyuratam railroad station in the Kazakhstan desert. However, it became quickly clear to the commission that neither of the two first options were feasible. The forest in Mordovia was too close to population centers and maintaining secrecy would be a challenge; and the area in Dagestan was surrounded by hills that made radio contact impossible during

19 Moscow selected Kapustin Yar as the first ballistic missile test range because of its access by rail and relative proximity to industrial infrastructure in the city of Stalingrad (Volgograd) on the Volga River. During the early years, the Soviets tested here V2 missiles captured from the Germans at the end of World War II. On 18 October 1947 the first rocket—a German A-4—blasted off the range. It was at Kapustin Yar on 2 February 1956 that for the first time a missile (an R-5M) carried a live nuclear warhead, which detonated 1,200 km downrange. When first built, Kapustin Yar was only a tent city; in a somewhat ironic twist of history, the tents used were U.S. Army tents—part of the Lend-Lease Program (1941-1945) designed to provide assistance to the Soviets against Hitler. (Stine, p. 133).
Kapustin Yar was not only the site of the first Soviet rocket launch and first missile launch with a live nuclear warhead, it was also the site where an entire class of Soviet missiles was eliminated. With the assurance that U.S. national reconnaissance and on-site inspections could provide the needed verification, in 1988 Moscow and Washington signed the Intermediate Nuclear Forces (INF) Treaty. In July of 1988, eliminations were begun at the Kapustin Yar Missile Test Complex with the elimination of the first SS-20 missile. The last was eliminated on 12 May 1991.

launch. Tyuratam was ideal—situated on a rail line in an extremely sparsely populated area of Kazahkstan. Moscow approved the site for the new work, and code-named it "Taskhkent-50" (Rhea, p. 322ff).

Initially life at Tyuratam was extremely hard. People stationed there could not tell anyone where they worked. Beginning early construction in 1955, the first Tyuratam commander—some five decades later—describes it as having been a "hell hole," noting: "The early construction phase was particularly arduous for everyone involved. We simply had to bite our lips and get on with the work, keeping in mind its importance for our country" (Rhea, p. 336).

The actual construction of the launch range and pad began in 1955 (and was finished by 1957); the first static test firings of the R-7 began in February 1956. However, there were numerous challenges. For example, transporting the test missile became a major challenge, since it was too large to be transported in an assembled state. Moreover, the liquid oxygen missile was extremely dangerous to fuel if not done properly and carefully.

Finally, however, by February of 1957 Korolev began preparing for the first launch. The first launch scheduled for March, however, was unsuccessful and had to be called off before liftoff. A second attempt in April also failed to launch. Finally on 15 May 1957, the first R-7 finally lifted off the pad. But it exploded over the test range. Korolev wrote to his wife: "...my frame of mind is bad. I will not hide it. It is very difficult to get through our failures...There is a state of alarm and worry..." (Zaloga, 1993, p. 144). Then, another attempt in June failed. Finally, on 21 August 1957, Korolev successfully launched his R-7 ICBM.

Soviet technological breakthroughs between 1957 and 1961 were undeniably due to the genius of Sergei Korolev. But during the 1950s as he worked furiously to get the R-7 working, he was technically still a "non person." It was not until 19 April 1957 that the Khrushchev government finally notified Korolev of his rehabilitation. On that fateful day in August of 1957, Korolev almost certainly enjoyed a brief moment of sheer wonder. After so many failed launches, the ICBM successfully launched and the dummy payload soared some 6,400 kilometers, eventually landing near the Kamchatka peninsula, not far from Kolyma where Korolev had barely survived the *Gulag.*

U.S. Lack of Knowledge: Fear in Lieu of Hard Data, While Searching for Technical and Scientific Solutions, 1957–1960

> *"We have found no evidence in Russian foreign and military policy since 1945 to refute the conclusion that U.S.S.R. intentions are expansionist...The evidence clearly indicates an increasing threat which may become critical in 1959 or early 1960."*
>
> —*The Gaither Report,* 1957

> *"Strategic warning...will become even more valuable as the maximum achievable tactical warning time shrinks to a matter of minutes in the case of a missile attack."*
>
> —*The Gaither Report,* 1957

> *"Let me return to that memorable year, 1957. Our missiles had made the United States tremble."*
>
> —Former Soviet Premier Nikita Khrushchev, *Memoirs,Vol. II,* p. 458.

Even though press and public criticism of the Eisenhower Administration had been growing since Soviet and Chinese actions in the Mideast, Indochina, and Hungary in 1956, it was only after *Sputnik* the following year that it reached a fevered panic. The object causing the panic was merely a 22-inch sphere weighing only 183 pounds, traveling in an orbit that took it around the Earth every 96 minutes. As one expert has noted, it was actually quite an "unspectacular satellite that probably should not have elicited the horrific reaction it wrought" (Launius, p. 2). Be that as it may, perhaps the greatest source of apprehension was the fact that the "unspectacular satellite" was passing *over* the United States four to six times a day.

However, what the public and press did *not* know—and *could not* know—was that Eisenhower, as early as 1954, had been extremely worried about the impending Soviet threat and acutely aware of the lack of hard intelligence. After the dire warnings of the 1955 classified Technical Capabilities Panel—that the Soviets were already capable of delivering a "fatal" first attack—he had authorized classified U-2 overflights and the development of a classified photoreconnaissance satellite, known as Corona.

In 1954 President Eisenhower had tasked the Science Advisory Committee to study the issue of the danger of a surprise attack on the United States. Presenting its findings to the National Security Council in February 1955, the Technological Capabilities Panel (TCP) was composed of more than 40 scientists and engineers, headed by Dr. James F. Killian, President of the Massachusetts Institute of Technology (MIT). Their two-volume findings—*Meeting the Threat of Surprise Attack*—focused on three areas of national security: continental defense, strike forces, and intelligence. Dr. Edwin H. "Din" Land, founder of Polaroid, was put in charge of the third section on intelligence.

Key findings of Din Land's panel included praise of existing *National Intelligence Estimates* (NIEs) while stressing, however, that analysis could not replace hard facts. The sub-group[20] believed the Soviets had already altered the strategic balance: as of 1955, they believed [mistakenly], the Soviets had enough TU-4 bombers with nuclear devices that could, on one-way missions, reach most targets in the U.S.—and deliver a "fatal" first attack. Moreover, the intelligence panel was particularly concerned about the lack of

20 According to Curtis Peebles, Din Land insisted that no committee should be larger than the number of people who fit into a taxicab. Thus, the unofficial name of the intelligence sub-section became "the Taxicab Committee." See Peebles account, *The Corona Project,* p. 19ff.; and Victor McElheny's biography on Din Land, *Insisting on the Impossible,* p. 294ff.

hard data on what the Soviet capability was with respect to long-range ballistic missiles. Indeed, the sub-section woefully noted that the U.S. knew "next to nothing" (Killian, p. 16).

The TCP findings stressed that offensive capability was just as critical as defensive; the U.S. must proceed as quickly as possible with developing ICBMs but in the meantime should proceed with developing Intermediate Range Ballistic Missiles (IRBMs); that the U.S. needed to urgently develop an aerial reconnaissance capability—preferably to be undertaken not by the Air Force, since it would take too long; that this capability was urgently needed; and finally that the U.S. also needed to embark on a satellite reconnaissance program.[21]

Unaware of these classified developments, however, it was a beeping object orbiting in space—whose emissions actually meant nothing—that fully escalated fear both in the U.S. and throughout the world. While TASS had announced the August ICBM launch, the world had taken little note of it.[22, 23] In the panicked reaction to *Sputnik*, Eisenhower was criticized for being in "partial retirement" and a golf-playing, do-nothing president; the Democratic Governor of Michigan even wrote a satirical poem ridiculing him:

Oh little sputnik, flying high
With made-in-Moscow beep,
You tell the world it's a Commie sky
And Uncle Sam's asleep.

You say on fairway and on rough
The Kremlin knows it all,
We hope our golfer knows enough
To get us on the ball.

—Michigan Governor G. Mennen Williams
(See Roger Launius, "Sputnik and the Origins of the Space Age")

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21 It was actually a May 1946 report that had first highlighted the need for the development of satellites, since satellites would "offer an observation aircraft which cannot be brought down." See McDougall, p. 89. The term "RAND" to name the think tank is derived from **R**esearch **an**d **d**evelopment.

22 TASS (Telegraph Agency of the Soviet Union) collected and distributed internal and international news for all Soviet newspapers, radio, and television.

23 Between 1951 and 1957, the Russians had made more than 20 announcements that they were headed for space (Dickson, 96). With the August launch, they warned the world that it was now possible "to direct rockets into any part of the world." But the announcement was not taken seriously in the West. Even the editors of *Time* magazine puzzled over the lack of attention or media coverage in the West of the first ICBM, noting "...the public consciousness and the front pages of the U.S. were occupied largely by domestic matters—the closing battle in Congress, the Teamsters scandal, inflation." See "The Nation: Red Moon Over the U.S." in *Time*, 14 October 1957.

Even though *Sputnik* only transmitted intermittent beeps with no meaning—chirping in the key of A-flat lasting three-tenths of a second, followed by a three-tenths-of-a-second pause—it sowed havoc among Western intelligence analysts. Reportedly, analysts at CIA, Defense Intelligence Agency, Army, Air Force and other Western intelligence agencies worked day and night to see who would be first to decipher the beeps. Columnist Stewart Alsop even suggested that the *Sputnik* "might have eyes to see" (Dickson, p. 113ff).

The element of surprise is what was most jolting: even though the West knew that the Soviets had been making plans for launching a satellite, few in the West actually believed the Soviets were capable of such technological skill. Americans had nothing but disdain for the quality and scarcity of Russian material goods, viewing Soviet cars as decidedly humorously inferior and Soviet consumer goods as being remarkably shoddy, even when available—which was not often.

Sputnik also finally brought world attention back to the August ICBM launch. The American labor leader Walter Reuther referred to Sputnik as a "bloodless Pearl Harbor"; Senator Henry Jackson bluntly declared that the U.S. was "losing the race for the ICBM"; *The New York Times* warned that the U.S. was in a race for survival; Senators Mansfield and Javits called for an immediate "Manhattan Project" approach to missiles and space (Levine, p. 61); and the British *Guardian* pointed out that the Russians could now build ballistic missiles capable of hitting any chosen target anywhere in the world, and that Moscow undoubtedly had a "great lead" in missile technology (Harford, p. 9).

But it was a leak to *The Washington Post* of the classified *Gaither Report* in December, 1957—and the manner in which the Post reporter presented it—that seemed to encapsulate the fears aroused by *Sputnik.* In the previous spring, under the aegis of the Pentagon, the Defense Mobilization Science Advisory Committee, composed of some of the country's leading scientific and defense experts, had begun a general inquiry on U.S. civil defense, but gradually broadened their focus to include U.S. defense policy in general.[24] The scientists and defense experts issued their findings in November 1957. Though the report was classified, the "Security Resources Panel Report"—or the *Gaither Report* as it came to be known—by December had been leaked to *The Washington Post,* and was to become instrumental in stoking public fear.

Not unlike the 1955 TCP findings, the 1957 *Gaither Report*[25] stressed that the U.S. had "...too few solid facts on which to base essential knowledge of U.S.S.R. capabilities...." (*Gaither,* p. 10). The authors of the *Gaither Report* believed the Soviet threat was not merely to be found in the degree of Soviet capabilities in 1957, but primarily in the astonishing pace of development and technological breakthroughs by the Soviets, particularly in light

24 Though now widely referred to as "The Gaither Report," H. Rowan Gaither—a co-director of the study group—became ill in the Spring of 1957 just as the group began its study. See Killian, p. 96ff.

25 Much has been written about the *Gaither Report.* Historians no longer differ on the importance of and the impact of the study. Of some controversy still, however, is the role and intentions of the drafters of the report. Most recently, Richard Rhodes concludes that Paul Nitze and his colleagues on the Gaither Panel—while "victim" to then-current exaggeration of Sino-Soviet advances in 1957—nonetheless *intentionally* "chose to exaggerate the dimensions of the threat." See his *Arsenals of Folly,* p. 109ff.

of the country's poor economic state in 1945. Somewhat marveling at the Soviet recovery, the Panel members assessed that the Soviets "have probably surpassed us in ICBM development" (*Gaither*, p. 4). They warned that the very survival of the U.S. was at stake, and urged "...exploitation of all means presently at our disposal to obtain both strategic warning and hard intelligence, even if some risks have to be taken..." (*The Gaither Report*, p. 10).

Most alarming in the Panel's findings was their belief that as early as 1959 the Soviet Union might have the capacity to launch a surprise ICBM attack—that the USSR would have the capability to launch a destructive first strike.

On 20 December 1957 journalist Chalmers M. Roberts in *The Washington Post* front-page headlines ominously warned that the "still top-secret Gaither Report portrays a United States in the gravest danger in its history" (Roberts, 1957). The U.S. was in danger of becoming a "second-class" power; there was an "immediate" threat from the "missile-bristling Soviet Union" (Roberts, 1957).

But despite public derision after Sputnik, President Eisenhower had quickly taken decisive action. Immediately after Moscow's August 1957 successful ICBM launch, the U.S. Strategic Air Command (SAC) initiated a 24-hour/7 days a week nuclear alert—an alert that remained in effect until 1991. In November 1957 President Eisenhower made the decision to begin stationing Intermediate-Range Ballistic Missiles in Europe—missiles within striking range of Moscow.

With some fluctuation, the tension between the two superpowers appeared to harden between 1957 and 1960, and into the 1960s. What did not help in easing tensions was the personality style of Nikita Khrushchev, whose public threats about Soviet superiority have become legendary. As one expert has noted: "He [Khrushchev] decided to trump American nuclear superiority with Soviet nuclear brinkmanship, using nuclear missiles as the last argument during international crises. His choice resulted in the most dangerous Soviet ventures during the entire Cold War" (Zubok, 2007, p. 124).

During this period, articles began to appear on a regular basis in the press about the so-called "missile gap"—i.e., that the Soviets were far ahead of the U.S. in ICBM development and deployment. In Congressional hearings, the topic was heatedly debated by politicians and defense experts, with Missouri's Democratic Senator Stuart Symington claiming that the U.S. was "asleep at the missile switch" (*Time*, 1959). In the February 1959 article ("Defense: Gap Flap"), *Time* magazine editors claimed that by 1961 the Russians would have four times the number of ICBMs as the U.S.

In the aftermath of *Sputnik*, Korolev proceeded to successfully establish other "firsts" in history with his R-7 launch vehicle. On 12 September 1959, the Soviets launched *Luna 2* from Tyuratam, impacting the moon and enabling the Soviets to claim one more first—the first spacecraft to reach another celestial body. Similarly, *Luna 3*, launched from Tyuratam on 4 October 1959, swung around the moon and, with the sun behind it, photographed the far side of the moon. The film was developed automatically onboard, scanned by a television unit, and transmitted by radio to the ground (Harford, p. 143ff). A few days after the *Luna 3* mission, a Soviet delegation presented copies of the photos of the moon's dark side to John Stapp, president of the American Rocket Society. Once again, the Americans were forced to admit that the Soviets had beaten them. Finally, Yuri Gagarin became the world's first man in space when he orbited the Earth a single time (in one hour and 48 minutes) on 12 April 1961.

1960: What Did the U.S. Know about Soviet Capabilities?

The lack of intelligence on Soviet strategic capability, needless to say, became even more alarming with the May 1960 Soviet shootdown of the "Operation Grandslam" U-2 mission. When President Eisenhower in 1956 had authorized the CIA to undertake the daring and badly needed U-2 flights, intelligence analysts were astounded with the first photographs of missile bases and launch sites such as Tyuratam. However, often these images were enough to merely stoke fears that there were many more sites in the USSR than the U.S. knew about. Indeed, in July 1960, the CIA estimated that only about 13.6 percent of area in the USSR suitable for ICBM deployment had actually been covered by U-2 imagery (McDonald, p. 332). Analysts, trained to continuously question—what Secretary of Defense Donald Rumsfeld in 2002 came to refer to as the "known unknowns" and the "unknown unknowns"—were deeply concerned about the remaining 85 percent of Soviet territory.

Intelligence collection against the Soviet Union had been difficult ever since the World War II Four Powers Alliance had begun to break down in the late 1940s. The Soviet Union was vast, spread over one of the largest areas of the Earth, with some 11 time zones. In an effort to consolidate the 1917 Bolshevik revolution, in subsequent years the Soviets had erected a highly repressive, centralized police state, where citizens were routinely spied on by the intelligence apparatus, taken into custody without warning, tortured, summarily shot, forced into confessions during a series of show trials in the 1930s, and often simply disappeared into the vast *Gulag* throughout Siberia. Although some of the harsher aspects of the repressive police state were somewhat ameliorated after Stalin's death in 1953, the apparatus of the repressive police state, the KGB and its predecessors, along with a highly disciplined Communist Party elite were irrevocably in place, and were to dominate Soviet culture and society until *Glasnost.*

With the emergence of the Cold War in the late 1940s, gaining intelligence against the Soviet adversary became a critical necessity for the West, particularly since it often appeared as if the Soviet Union's intentions were expansionist, in accordance with classic Marxist-Leninist-Stalinist ideology. The National Security Act of 1947 created many of the institutions—particularly the National Security Council (NSC) and the Central Intelligence Agency (CIA)—that were to emerge on the forefront of countering the emerging superpower during the Cold War. But the Soviet Union was what later became known as a "hard target," meaning penetrating behind the doors of the highly secretive Kremlin to discern intentions—much less capabilities—was to become a major challenge in coming years. Attempting to recruit human assets behind the Iron Curtain was practically impossible and fraught with danger.

Some of the best early intelligence on the USSR came from captured German aerial photographs that had been taken during World War II (Gaddis, 1997, p. 103ff). In particular, intelligence on early Soviet missile development was woefully inadequate and came from the British MI 6. In a rather daring operation, in 1948 British intelligence officers had posed as archaeologists in Iran and were able to monitor the Soviet test range at Kapustin Yar. But as late as 1950, the CIA had three analysts looking at Soviet missiles (Prados, pp. 57-58).

Since late 1946 when the U.S. first began spy flights along the coast of Siberia under the Peacetime Airborne Reconnaissance Program (PARPO), some—but limited—intelligence had been gained from flights along the periphery of the vast Soviet empire. These flights were only along the periphery—not directly over Soviet territory—but did yield limited intelligence about Soviet air defense, radar, and communication systems (Taubman, P., p. 47; Lindgren, p. 24ff). On 10 May 1949 USAF First Lieutenant Bryce Poe II undertook the first overflight over Soviet territory—the Kuril Islands in the Soviet Far East. Limited peripheral flights were made during the Korean War, and the U.S. Air Force and Navy planes undertook short-range penetration of Soviet and Chinese airspace.

Reportedly, it was actually the British who undertook the first deep overflights, beginning in 1951 and 1952 (Peebles, p. 19). These sorties entailed British RAF Special Duty Flights over Soviet facilities in the Baltic states, Poland, Belarus, Germany, Czechoslovakia, and the Ukraine. It was an RAF Special Duty Overflight in 1953 that snapped the first photograph of Kapustin Yar, where the Soviets had been undertaking missile testing since 1947. This intelligence from the British not only prompted Eisenhower to assemble the Teapot Committee charged with streamlining U.S. missile efforts, but also prompted him to authorize U.S. overflights (Reed, 43).

Overflights initially gave Eisenhower confidence in the adequacy of deterrence. This confidence was eroded, however, as the Cold War widened and deepened and new weaponry permanently altered the world geopolitical landscape in the 1950s.

Ironically to some degree, it was the deluge of photographs from the U-2 program, in conjunction with the sheer size of the USSR, that tended to lead to "worst case" scenarios in Washington, such as the so-called "missile gap" in the late 1950s. As indicated, analysts would extrapolate from the approximately 14 percent of the USSR that the U-2 covered, and assume that in the remaining 86 percent of the USSR there might be many more missile sites and indeed—after August of 1957—actually deployed and operational ICBMs. Arguably, this lack of hard intelligence—and fear about the "unknowns"—not only set in motion the establishment of large U.S. and Soviet defense bureaucracies during the 1950s, but also accelerated the efforts by both sides to quickly develop strategic missile capabilities.

On balance, during the initial stages of the Cold War—between 1947 and 1953—the U.S. tended to underestimate Soviet capability. The general underestimation tended to rest on the assumption that the Soviets were technologically far inferior to the U.S.[26]

Beginning in 1953—in the wake of the Soviets' unexpected hydrogen bomb test and with the results of the initial British imagery that had located Kapustin Yar—the U.S. began to step up efforts to improve its own intelligence collection. By early 1954 and 1955, the U.S. was gaining intelligence on early Soviet missile and technical development via collections stations in Turkey. The long-range radar station in Turkey was intended to keep track of Soviet missiles and was helpful—the U.S. was able to obtain some initial telemetry data of testing at Kapustin Yar. However, these radars could not discern the failures on the launchpad or shortly after launch; nor could they detect telemetry from missile launch activity at Tyuratam. The U.S. would have to wait another six years to be able to do that via national reconnaissance satellites (Zaloga, 1993, p. 152; Lindgren, p. 45; Garthoff, p. 147; Stine, p. 160).

Key targets for initial U-2 photoreconnaissance missions in the 1950s were: the intermediate missile (IRBM) test ranges at Kapustin Yar and Sary Shagan where medium-range ballistic missiles (MRBMs), intermediate-range ballistic missiles (IRBMs), and surface to air missiles (SAMs) were being developed. These early U-2 flights from 20 June to 10 July in 1956 also quickly dispelled the notion that there existed a "bomber gap," intelligence that the White House subsequently used to deny Air Force requests for additional B-52 bombers (Pedlow, p. 111ff).

Unexpected crises—where the U.S. and the West had had no prior warning of impending Soviet action—understandably accelerated efforts to gain more intelligence. Reportedly, it was the unexpected Soviet invasion into Hungary in 1956 that convinced Eisenhower to authorize renewed U-2 flights over the Soviet bloc (Pedlow, p. 123ff).

Although U-2 flights only covered a small percentage of Soviet territory, once a site had been identified, the U.S. could on a regular basis monitor developments at the site. Thus, after the August 1957 U-2 flew along rail lines and confirmed the presence of Tyuratam, it subsequently even took images of the R-7 on its erector launchpad. The U.S. was able to monitor early missile testing activity at Tyuratam until May of 1960 when the shootdown of Gary Powers ended the U-2 flight program.

By mid-1958—after the discovery of Tyuratam, the publication of the *Gaither Report,* and the Soviet's successful ICBM launch—searching for *deployed* ICBMs (the missiles with the range capable of hitting any U.S. city within minutes) became a major intelligence

26 During the past decade, CIA's Center for the Study of Intelligence (CSI) has published a number of excellent analytic essays and collections focused on U.S. estimates during the Cold War. The reader is recommended to begin with: the collection of NIEs entitled *Intentions and Capabilities: Estimates on Soviet Strategic Forces, 1950–1985,* edited by Donald P. Steury; the extremely insightful collection of articles in *Watching the Bear: Essays on CIA's Analysis of the Soviet Union,* edited by Gerald K. Haines and Robert E. Leggett; the collection of early *NIEs* in *Selected Estimates on the Soviet Union, 1950–1959,* edited by Scott A. Koch. For more information, the reader is advised to go to CSI's unclassified website at https://www.cia/gov/library/center-for-the-study-of-intelligence.

priority. By mid-1958, no *operational* ICBMs had been located (Lindgren, p. 49). In late 1959 an NIE (11-8-59) pointed out that the U.S. U-2 flight program had still not identified *operational* ICBMs. Ironically, the 1 May 1960 tragic Gary Powers U-2 flight flew over the Tyuratam ICBM Test Complex and was enroute to the Plesetsk area when it was shot down by an SA-2. Central Intelligence Agency analysts suspected ICBMs might possibly be deployed in the Plesetsk area, but did not know (Lindgren, p. 57).

The greatest degree of wild exaggeration in estimates of Soviet capabilities occurred in the period between 1957 and 1961. As a senior intelligence officer has astutely noted, it was in the "panicked reaction to Sputnik and the first Soviet ICBM test in August 1957...when overestimates began" (Garthoff, p. 5). These NIEs, beginning in late 1957 through mid-1961, by and large tended to particularly overestimate the Soviet ICBM capability. *National Intelligence Estimate 11-10-57* in December 1957 estimated there would be 100 ICBMs deployed by mid-1959 and possibly 500 ICBMs in mid-1961. A 1959 *NIE* predicted the Soviets had between 140 and 200 ICBMs. In reality, the actual number in 1961 was four (Garthoff, p. 5).

It was Corona that ultimately was able to resolve the so-called "missile gap"–i.e., the fear that the Soviets had far more long-range missiles than the U.S. did. More specifically, it was Corona Missions 9017 (July 1961) and 9023 (August 1961) that confirmed that there was no missile gap. Thus the following *NIE 11-8/1-61,* using the "take" from these two Corona missions, estimated the number of ICBM launchers to be 10 to 25—a sharp reduction from the NIE 11-8-59 prediction of 140 to 200 Soviet ICBMs (Lindgren, p. 105; Gartoff, p. 5).

The first Corona images of Plesetsk—one of the targets of Gary Powers' ill-fated May 1960 U-2 flight—was developed in November of 1960, revealing only four operational, deployed ICBMs at Plesetsk—not the *hundreds* intelligence estimates had thought. Indeed, the U.S. intelligence analysts then found themselves puzzling over other enigmas: were there other sites with deployed ICBMs? And what had happened to the Soviet missile program?

1960: Real Soviet Capabilities—The Gambit and Hexagon Legacy

> *"What gave rise to the legend that the Soviets were ahead and the United States was lagging behind? We actually were the first to begin testing intercontinental missiles. We were twelve to eighteen months ahead there and several months ahead in medium-range missiles. The reason is very simple: we were in a great hurry, while they [the U.S.] were not....The intercontinental ballistic missile was the Soviet Union's last hope for parity in the arms race."*
>
> —Nikita Khrushchev, *Memoirs Vol. II*

> *"My only regret after thirty years of developing missiles and space launchers is that it took until the end of 1975 before we managed to deploy a truly effective missile system."*
>
> —Nikolai Nillayevich Smirnitskiy in 1995, Served as Deputy Commander-in-Chief of the Strategic Rocket Forces, 1949–1975 (Rhea, p. 115)

In retrospect, it was actually only a few short years, between 1957 and 1961, that an argument could be made that at least briefly, the U.S. was "losing" the arms and space race. Beginning in August of 1960, Corona imagery revealed to what degree the *NIEs* had widely exaggerated the number of Soviet missiles. But it would be Gambit imagery—KH-7 beginning in 1963, and particularly higher-resolution KH-8 imagery beginning in 1966—that would enable insight into the technical challenges facing the Soviet missile program, challenges that caused the Soviet missile program to lag behind that of the U.S. by the early 1960s, after Moscow's initial successful salvo. In short, it was Gambit and later Hexagon—in conjunction with overhead sigint platforms—that could address the July 1960 U.S. Intelligence Board SIRC report on urgent intelligence gaps, and calling for *greater search* and *surveillance*, more *detailed* intelligence on ICBM installations and *greater technical specificity*.

What Gambit and Sigint platforms began to reveal was that despite the 1957 "firsts," the Soviet program from its very inception had been plagued by a series of problems—many technical, many due to the poor Soviet economy, and some due to the direction the early Soviet missile program had taken. After his successful R-7 ICBM launch, Korolev went on to use the R-7 launch vehicle to achieve his greatest accomplishments in the space race—where his heart actually lay. But his R-7 launch vehicle—while serving as an excellent space launch vehicle—was ultimately not a successful foundation for a Soviet ICBM deployed arsenal. Indeed, subsequent experts—while acknowledging Korolev's outstanding achievements, particularly in space—have used varying pejorative terms in describing Korolev's R-7 as an ICBM: as a "monster" (Stine, p. 242) and a "blunder" (Levine, p. 46).

Between 1957 and 1960, however, the Soviets did not appear to be aware of the R-7 shortcomings. Moscow had ambitious dreams. For example, it planned 12 launchers for Tyuratam. (Only four were eventually built.) Khrushchev himself was one of the most enthusiastic supporters of Korolev's missile, planning a plethora of missile bases throughout the U.S.S.R., and in 1959 creating the Soviet Strategic Rocket Forces—a group of carefully selected Soviet soldiers to form an elite force. He and the inner circle of the Politburo believed that focusing on building a large strategic arsenal would also help the USSR deal with its persistently dismal poor economy, allowing Moscow to cut back on its very large and expensive standing conventional army.

From its very inception, however, the Soviet program had been beset with constant delays due to the poor state of Soviet industrial capability. This is particularly seen in the difficulties in the construction of Plesetsk, one of the critical targets of Gary Powers' May 1960 ill-fated U-2 mission. Building Plesetsk (in the northwest corner of the U.S.S.R., not far from the Baltic Sea) was important to Moscow because the R-7 range of 8,000 km was not sufficient for Korolev's missile to reach the entire U.S. from Tyuratam. Work to construct the base began in July of 1957. But not unlike many Soviet undertakings, due to persistent problems in material (e.g., the poor Soviet metallurgy capability) and lack of needed construction supplies, there were constant delays in finishing the range at Plesetsk. Indeed, because of the continuous delays, at a 1958 Plesetsk program review meeting Khrushchev's temper supposedly exploded, and he cancelled the entire Plesetsk program. He relented, but the R-7 deployment was scaled back.

Meanwhile, between August of 1957 and April 1958, Korolev proceeded with a flurry of further testing of his R-7 at Tyuratam, some 10 to 15 tests in all. However, none of these flights went beyond 6,000 kilometers. Then there was a pause in testing until March 1959. Why? What had happened to the Soviet program?

Between 1960 and 1966, Moscow actually was only capable of deploying a limited number of operational ICBMs [See Table 1]—not the feared hundreds in *NIEs.* By the mid-1960s the Soviets would be able to recover from the delay to some degree, but it was not by relying on the R-7 or even its R-9 successor, but by building the bulk of its fleet of long-range ballistic missiles from the shop of one of Korolev's rivals, Mikhail Yangel. It was Yangel's R-16 series—and by 1970 Vladimir N. Chelomei's UR-100 series—that were to comprise the backbone of the deployed Soviet ICBM fleet.

Korolev's R-7 series proved to be an erroneous start, due to multiple factors. Some examples:[27]

Sheer size and weight of initial hydrogen warheads. Korolev's early missiles had to be extremely large in order to carry and launch the massive early thermonuclear warheads. For example, the R-7 payload was 5.4 tons compared to the U.S. Atlas with a payload of only 1.8 metric tons. Gradually, however, the Soviets began to develop the capability of reducing the size and weight of thermonuclear warheads—such as those mounted on Korolev's R-9 (Zaloga, 1993, p. 192 ff).

Consequent sheer size of booster. This tremendous size and weight of initial Soviet hydrogen warheads meant that the R-7 had to be very large, adding additional transportation and production challenges. However, even aside from the early hydrogen warheads, the unwieldy weight of the booster was also a result of Soviet backwardness in metallurgy (Levine, p. 45). In contrast, Yangel's R-16 had a throw-weight only a third of the R-7's and a more compact warhead.

Lack of strategic surprise—time delay due to the type of fuel. While the U.S. had solid fuel as early as 1962 (the Minuteman), solid fuel motors were outside Soviet technological capability at the time (Zaloga, 1993, p. 193). Korolev used liquid oxygen (LOX), whereas Yangel used hypergolic fuel—nitric acid as the oxidant and an improved kerosene derivative. Both types of fuel had disadvantages: as liquids, they were both extremely volatile and dangerous. But Korolev had a long-standing aversion to hypergolic-fueled rockets and called Yangel's nitric acid "the devil's venom." His fuel—unwieldy and impractical—could not remain in the missile for any length of time; sun and heat caused LOX to change back to its natural gaseous state. Thus, Korolev R-7 missiles required

27 Beginning with *Glasnost* in 1989, and with the opening of many Soviet archives after 1991, the West has gradually been gaining even more precise understanding of Soviet missile and space development. For some of the more insightful secondary sources in recent years, see Mike Gruntman's *Blazing the Trail; Russian Strategic Nuclear Forces,* edited by Pavel Podvig; Alan Levine's *The Missile and Space Race;* G. Harry Stine, ICBM; Steve Zaloga's *Target America* and *The Kremlin's Nuclear Sword;* and James Harford, *Korolev.*

24 hours to ready for launch, whereas Yangel's fuel could sit in a missile for as long as six months and required only 30 minutes to fuel. This slow launch time in Korolev's missiles became even more critical after 1959 with the development of early warning radars (Khrushchev, p. 459ff). To evade radar detection, the Soviets needed to develop a missile capable of being launched within 30 minutes of warning.

Guidance system. What the West did not know in 1960 is that the USSR had not solved the guidance system problem. While the R-7 had reached a range of 7,000 kilometers, the USSR could only direct it to a target by placing radio guidance systems every 500 kilometers along the way—making the R-7 unreliable (Levine, p. 46; Khrushchev, p. 459; Taubman, W., p. 379).

Even aside from the drawbacks of Korolev's R-7 missile, however, there were delays in production, development, and deployment of both Korolev's and Yangel's types of ICBMs due to a multitude of factors. Some examples:

Both the R-7 & R-16 series were hastily made. The R-7, R-8, and the R-16 were rushed as Moscow—lacking strategic surprise capability in their intercontinental strategic bomber arsenal—saw ICBM deployment as Moscow's only viable offensive weapon against the U.S. For example, engine tests on Yangel's R-16 began in 1959 but by 1960 the first missiles began to move off the assembly lines at Dnepropetrovsk for shipping by rail to Tyuratam. This push to develop new missiles rapidly resulted in tragedy and setbacks to the Soviet program. For example, on 23 October 1960, an R-16 exploded on the launchpad at Tyuratam. Between 100 and 200 men were killed, including the Soviet Commander Marshall Nedlin and the leadership of Yangel's design team, leading to a major setback for the R-16 (Zaloga, 1993, p. 195ff). Tests of the R-16 did not resume until 1961.

Generally poor Soviet economy. At the time Sputnik was launched, requirements of new armament far surpassed allocated resources. Procurement costs for strategic missiles were about 1.4 million rubles apiece in 1962 prices; funding for the strategic program was often lacking, with Moscow, for example, at one point having to scrap the last three years of the Five-Year-Plan (Zaloga, 1993, p. 152).

Basing systems and silos. At Tyuratam, the Soviets developed elaborate basing stations which in turn delayed the Soviet need to move to silos. The first R-16s deployed in 1962 used above-ground launch systems (Zaloga, 1993, p. 198ff).

Cost and challenges of silo construction. In 1961, Khrushchev had called for the construction of hardened silos. But this effort proved to be very difficult and expensive, resulting in many delays. The first of the "Sheksna" silo launch complexes were finally ready by 1964, but the majority of R-16 missiles remained based in unprotected coffin launchers.

By 1960 the Soviet program was faced with multiple challenges. Only a few days after Khrushchev's October 1960 United Nations speech where he bragged that the Soviet

Union was producing "missiles like sausages," the first of Yangel's R-16s exploded as it was being prepared for firing at Tyuratam (Harford, p. 118).

In short, due to a multitude of factors, by 1960 the Soviets actually had only about 20 operational missile launchers, most of which were untested or simply training models: four launchers at Plesetsk, several training launchers at Tyuratam, and new untested R-16 missile launchers being installed at Yura (Zaloga, 1993, p. 213). In contrast, the U.S. had 60 operational in 1960, so the so-called "missile gap" was simply a myth, capturing U.S. fears and lack of hard intelligence, but little more.[28] While Corona enabled "counting" of the real number of deployed ICBMs, it would be Gambit and Hexagon that would provide the type of technical detail and surveillance needed to understand the quality of Soviet ICBMs (allowing for example "continuous observing" of an ICBM site to discern fuel handling, silo loading etc). Among other capabilities, these systems enabled:

Penetration of Soviet ICBM silos. Between 1957 and 1960, the Soviets began to be concerned about the vulnerability of the nascent R-7 ICBM fleet. Thus, in 1961 Soviet Premier Nikita Khrushchev ordered the development of hardened missile silos, since silos would make it difficult for the U.S. to locate and verify the missile silos (Khrushchev, p. 463ff). Gambit and Hexagon were capable of doing what Corona had been unable to do—namely, locate and provide needed intelligence on the hardened silos.

Gaining intelligence on Antiballistic Missile installations. Between 1959 and 1963, the Department of Defense and U.S. intelligence analysts became increasingly aware that the Soviets were developing antiballistic missile installations. Analysts believed a site existed at Leningrad, but they needed greater specificity about it.

Surveillance of critical Soviet sites. Analysts needed to have continuous "watching" (surveillance) of ICBM sites in particular, intelligence that would allow them to gain a better comprehension of the Soviet ICBM program: How did the Soviets fuel the R-7? How long did it take? And as the Soviets began to build silos, how long did it take to load a missile? What could analysts learn about the technical characteristics of the missile by continuously watching Soviet Strategic Rocket Forces handle the R-7 over a period of days and even weeks?

Identification of materials of Soviet strategic arsenal. Since the U.S. had no means of covertly acquiring a Soviet ICBM and almost certainly no human assets in the U.S.S.R. that could assist in identifying the materials used in the missiles, U.S. intelligence officers needed imagery with resolution sharper than Corona imagery, imagery that would enable the U.S. to learn more about not only missiles, but also bombers, antiballistic radar sites, etc. Beginning in 1966, Gambit's KH-8 imagery would allow the U.S. Intelligence Community for the first time to assess technical capabilities of strategic systems, based on a

28 A great deal has been written about the so-called "missile gap"—a much too exhaustive bibliography than possible for this article. For an introductory overview, see David Lindgren's *Trust But Verify*; Neil Sheehan's *A Fiery Peace in a Cold War*; Alan Levine, *The Missile and Space Race*; and publications from CIA's Center for Studies in Intelligence (CSI).

clearer understanding of the materials used.

It was not until 1966 that the Soviets began to recover from their "misadventure" with the R-7 missile and Moscow began to actually deploy—in large numbers—Yangel's R-16 (50 in 1962 and 202 in 1965) [See Table 1]. And it would be the resolution of Gambit imagery in conjunction with the surveillance of Hexagon in conjunction with Sigint platforms that would allow the U.S. to gain insight into the technical characteristics of the Yangel's missiles, as well as greater insight into what had happened to the Soviet ICBM effort after the truly remarkable beginning between 1957 and 1960.

EARLY SOVIET BALLISTIC MISSILES: NOMENCLATURE

USSR Number		Western Number		Type	Designer
R-1	8A11	SS-1	Scunner	IRBM	Korolev
R-11	8A61	SS-1b	Scud-A	IRBM	Korolev
R-2	8Zh38	SS-2	Sibling	IRBM	Korolev
R-5	8A62	SS-3	Shyster	IRBM	Korolev
R-12	8K63	SS-4	Sandal	IRBM	Yangel
R-14	8K65	SS-5	Skean	IRBM	Yangel
R-7	8K71	SS-6	Sapwood	ICBM	Korolev
R-16	8K64	SS-7	Saddler	ICBM	Yangel
R-9A	8K75	SS-8	Sasin	ICBM	Korolev
R-36	8K67	SS-9	Scarp	ICBM	Yangel
UR-100	8K84	SS-11	Sego	ICBM	Chelomei

EARLY SOVIET BALLISTIC MISSILES: DEPLOYED

		Type	1960	1962	1965	1970
R-5	SS-3	IRBM	36	36	20	—
R-12	SS-4	IRBM	172	458	572	504
R-14	SS-5	IRBM	—	28	101	89
R-7	SS-6	ICBM	2	6	6	—
R-16	SS-7	ICBM	—	50	202	195
R-9A	SS-8	ICBM	—	—	26	26
R-36	SS-9	ICBM	—	—	72	270
UR-100	SS-11	ICBM	—	—	—	930

Table 1. Soviet Missile Deployments and Nomenclature, 1960–1970

Source: Mike Gruntman, *Blazing the Trail: The Early History of Spacecraft and Rocketry (2004).*

Why Gambit & Hexagon: Retrospect and Post-1960

"I have been shown photographs of airplanes taken from orbit by satellites. You can tell exactly what type of planes they are....I've seen [American] photographs. They are more precise than ours."

—Nikita Khrushchev, dictated Memoirs, 1966-1970[29]

29 Since he dictated/drafted his Memoirs between 1966 and 1970—and specifically refers to satellite imagery distinguishing airplane models and types—Khrushchev is probably referring to Gambit imagery. See the 2005 *Memoirs* edited by his son Sergei, p. 462.

> *"In the 1970s and 1980s the 'national technical means' of surveillance, as photoreconnaissance satellites were called, gave sufficient transparency through the Soviet Union's Iron Curtain that the U.S. could enter into strategic arms negotiations to control and eventually start to reduce the threat of nuclear weapons mounted on large delivery systems of intercontinental ranges.... compliance with treaty limitations could* be verified."
>
> —Sidney D. Drell, "Physics and U.S. National Security," *Review of Modern Physics, Vol. 71, No. 2 Centenary 1999,* p. S460.

The Gambit and Hexagon missions were accordingly a direct response to events between 1957 and 1960. The Soviet "firsts" shocked the American public, producing a near-panic that the 1957-leaked *Gaither Report* only intensified. As the broad American public became more aware of the danger posed by the new weaponry—particularly the horrifying implications of a Soviet ICBM force—U.S. government officials were actively finding solutions to counter not only the threat of a Soviet surprise attack, but the potential of a Soviet first-strike capability that might even entail the destruction of the West.

After its first successful launch in August of 1960, although the quality of Corona's imagery was initially not the best (particularly even compared to later Corona improvements), the Corona system irrefutably dispelled the "missile gap" myth. By 1961 the U.S. Intelligence Community was estimating the number of Soviet ICBM launchers to be 10 to 25—not the 140 to 200 estimated in the 1959 *NIE*. During 1961 and 1962, Corona discovered R-16 (Yangel) and R-9A (Korolev) ICBM missile complexes under construction at Yurya, Verkhnyaya Salda, Yoshkar Ola, Teykovo, Svobodnyy, Perm, Kostroma, and Itatka. In 1963, the Kozelsk, Drovyanaya, Gladkaya, Shadrinsk, and Yedrovo ICBM complexes were discovered. And by 1962, Corona had identified most of the Soviet MRBMs and IRBMs targeting Europe and Japan. As analysts began to produce National Intelligence Estimates with the benefit of Corona imagery, Sherman Kent astutely remarked that they were no longer "estimates," but rather "factbooks" (NPIC, p. 34, 35).

Drawing on this legacy, Gambit and Hexagon would fulfill in spades the July 1960 SIRC mandate that the U.S. needed greater surveillance and greater technical detail on Soviet strategic forces. High-resolution Gambit could provide the kind of specificity needed by scientific and technical (S & T) intelligence officers: for the first time, U.S. intelligence officers had detailed information and accurate mensuration data to develop engineering drawings on foreign weapon systems. The U.S., for example, was even able to carefully monitor the Soviet development of Yangel's R-16 and R-36. Hexagon could cover thousands of square nautical miles with contiguous, high-resolution imagery in a single operation, for intelligence and mapping, and charting, and could provide order-of-battle information across entire Soviet military districts. The two systems often worked in tandem, enabling regular monitoring at a site, thereby giving U.S. analysts greater understanding of the quality of Soviet strategic forces and weaponry, production, and helped identify military communications equipment, monitor types of Soviet aircraft, etc. As the Soviets began to develop a mobile missile force, the systems could monitor their early development and provide invaluable insight.

By the 1980s, however, technological advances allowed the Soviets to produce lighter and more agile strategic weapons, with new types of mobile ICBMs and multiple reentry vehicle warheads (MIRVs). Accordingly, as one expert has noted, with the new technology, Moscow was able at least in the area of ballistic missiles to counter the powerful intelligence benefit of film-return systems such as Gambit and Hexagon. It was new U.S. national reconnaissance capabilities such as near-real time and other approaches that would assist in detecting and monitoring missiles with the new capabilities (Berkowitz, p. 109). However, monitoring mobile missiles and gaining greater detail about multiple warhead reentry vehicles had been made easier through two decades of Corona, Gambit, and Hexagon imagery locating and identifying all the missile and other strategic sites in the vast territory of the U.S.S.R., as well as providing the technical and specific data needed on the Soviet strategic program. Moreover, after two decades of analyzing Corona, Gambit, and Hexagon imagery, imagery intelligence analysts had developed the techniques and methodology of a honed "science."

Finally, in the Cold War stalemate, these systems played a critical role in enabling a significant thaw in tensions—the needed-verification mechanism (lacking in the 1950s during initial efforts to achieve a limitation on nuclear testing) for a series of arms control treaties: the Limited Test Ban Treaty, 1963; strategic arms limitation treaties (SALT I in 1972 and SALT II in 1979); and the Anti-Ballistic Missile (ABM) Treaty, 1972. In addition, the systems paved the way in the 1970s and 1980s for national reconnaissance near real-time imagery to provide verification, allowing Moscow and Washington to finally enact Eisenhower's "Open Skies" vision from the 1950s by signing the Treaty on Open Skies in 1992; and enabling the most comprehensive reduction of strategic weapons between Moscow and Washington, the 1987 Intermediate Range Nuclear Forces (INF) and the 1991 Strategic Arms Reduction (START) treaties.

It had begun in 1957 with the panicked reaction in the West for what had been unexpected and was truly remarkable about Korolev's achievements at Tyuratam, in rapid succession: the world's first ICBM, the world's first satellite, the first spacecraft to impact a celestial body *(Luna 2)*, the first photographs of the far side of the moon *(Luna 3)*, and the world's first manned spaceflight in 1961.

It had all started at Test Launch #1 at Tyuratam.

Figure 1. KH-8 Image of Space Booster at the Tyuratam Missile Test Center in the Former Soviet Union, 19 September 1968

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Chronology of Selected Key Events for "Why Gambit & Hexagon?"

Date	Event
6 Aug 1945	The U.S. drops a nuclear bomb on Hiroshima in an attempt to bring the World War II Pacific War to an end
22 Feb 1946	U.S. Charge d'affaires in Moscow George Kennan sends historic 8,000-word telegram to State Dept, warning of Moscow's alarming intentions in foreign policy
July 1947	U.S. Charge d'affaires in Moscow George Kennan outlines a policy of containment for dealing with Soviet expansion
26 July 1947	The U.S. Congress passes the National Security Act, establishing both the National Security Council (NSC) and the Central Intelligence Agency (CIA)
24 June 1948	Soviet Premier Joseph Stalin orders a blockade of all land routes from West Germany to Berlin
July 1948	Soviet physicist Andrei Sakharov begins development of "Layer Cake" concept for hydrogen bomb
15 May 1949	Communists win election in Hungary
29 Aug 1949	The Soviet Union successfully tests its first atomic bomb
1 Oct 1949	Mao Zedong establishes the People's Republic of China
31 Jan 1950	President Truman announces his decision to develop the hydrogen bomb
Feb 1950	Joint Intelligence Committee predicts buildup of Soviet atomic arsenal and possible attack against U.S. "at earliest possible moment"
16 Feb 1950	The Soviet Union and the People's Republic of China sign a pact of mutual defense (the "Sino-Soviet Pact")
24 Feb 1950	U.S. Joint Chiefs of Staff request "all out effort to build H-bomb"
7 Apr 1950	National Security Council document NSC-68 warns of surprise attack by Soviet Union once "it has sufficient atomic capability"
17 Apr 1950	Ambassador Paul Nitze issues NSC-68, with containment as the cornerstone of U.S. policy for the next 20 years
22 June 1950	North Korea invades South Korea
Mar 1952	The Royal Air Force and the Strategic Air Command begin flying photographic and radar reconnaissance missions over the Soviet Union
1 Nov 1952	The U.S. tests the world's first thermonuclear bomb at Eniwetok in the Pacific—10.4 megaton "Mike," nearly 700 times more powerful than bomb exploded at Nagasaki
Dec 1952	President-elect Eisenhower and staff develop "New Look" defense policy relying primarily on power of atomic forces
Aug 1953	General Edmundson leads "Operation Big Stick," which requires him to take 20 B-36s, armed with nuclear weapons, to Okinawa in Japan
12 Aug 1953	First test of Soviet thermonuclear device (Andrei Sakharov's "Layer Cake") takes place
End of 1953	Politburo charges Korolev with task of creating an ICBM large enough to carry the heavy Soviet hydrogen warhead
12 Jan 1954	Secretary of State John Foster Dulles announces administration policy of "massive retaliation" in response to Communist attacks
21 Jan 1954	The U.S. launches the world's first nuclear submarine, the USS Nautilus
14 Sep 1954	44,000 Soviet troops take part in a military exercise involving the dropping of an atomic bomb via an aerial bomber

Date	Event
18 July 1955	The Geneva Summit takes place, attended by President Eisenhower, Prime Minister Anthony Eden of the UK, Premier Nikolai A. Bulganin of the Soviet Union, and Prime Minister Edgar Faure of France. However, talks to reach an arms control treaty eventually falter, due to the lack of verification capability
Nov 1955	Soviets successfully test the hydrogen bomb
Feb 1956	The Soviets hold their Twentieth Party Congress of the CPSU
20 June 1956	First U-2 overflight; Mission 2003 flies over Warsaw Pact countries
4 July 1956	First U-2 mission over the Soviet Union
5 July 1956	Second U-2 overflight of denied territory from Wiesbaden, West Germany. Mission 2014 photographs locations in Warsaw Pact countries, as well as Moscow. This mission dispels myth of the existence of the U.S.-Soviet "bomber gap
10 July 1956	U-2 stand-down ordered after Soviet Union lodges formal protests of repeated American violations of Soviet and East Bloc air space
Aug 1956	Project Rainbow begins in first-ever attempt to make operational aircraft stealthy by adding radar-cancelling devices to the U-2
July–Oct 1956	Suez Crisis: After Egyptian President Nasser nationalizes the Suez Canal, France, Israel, and the UK attack Egypt
29 Aug 1956	U-2 reconnaissance overflights of the Middle East seek evidence of war preparations
4 Nov 1956	Soviets invade Hungary
20 Nov 1956	U-2 overflights resume with Mission 4016, piloted by Francis Gary Powers
Aug 1957	U-2 overflight confirms the existence of a suspected Soviet ICBM test site at Tyuratam (Baikonor)
28 Aug 1957	U-2 Mission 4058 photographs locations in and around Dushanbe, Tashkent, Tyuratam, Kazalinsk, and Aral Sea regions in the USSR
Aug 1957	Soviets successfully test the world's first ICBM (Korolev's RS-7)
1 Oct 1957	The U.S. Srategic Air Command (SAC) initiates a 24/7 nuclear alert in response to Soviet ICBM capability—a 24/7 nuclear alert that remains in effect for the next three and a half decades (1991)
4 Oct 1957	Soviets successfully launch the world's first satellite from Tyuratam on a Korolev R-7 booster—*Sputnik*
Aug 1958	The U.S. deploys Thor Intermediate-Range Ballistic Missiles (IRBM) in the U.K., within striking distance of Moscow
Sep 1959	From Tyuratam, Soviets successfully launch Luna 2 with a Korolev R-7 booster—the first spacecraft to reach another celestial body when it impacts the moon
Oct 1959	Soviets launch *Luna 3*—from Tyuratam, on a Korolev R-7 booster
31 Oct 1959	The U.S. deploys the first operational intercontinental ballistic missile (ICBM), the Atlas D
Dec 1959	Soviet Premier Nikita Khrushchev creates the Soviet Strategic Rocket Missile Force with the underlying belief that strategic nuclear missiles could serve as the basis of the Soviet armed forces, and by augmenting a reduced conventional force, would help Moscow's ailing economic straits
Apr 1960	Jupiter IRBM deployment to Italy begins: ballistic missile within strike range of Moscow
1 May 1960	The Soviet Union shoots down Francis Gary Powers' U-2 reconnaissance plane. Key targets of the mission were Tyuratam, Kyshtym, and Sverdlovsk
June 1960	Khrushchev at UN Assembly in New York pledges support for "wars of national liberation" throughout the world
15 July 1960	U.S. Satellite Intelligence Requirements Committee (SIRC) submits report to the U.S. Intelligence Board calling for Corona follow-on satellite systems with a greater search system (capable of locating suspected ICBM launch sites at a resolution of 6 meters on a side), and a system with a resolution approaching 1.5 meters in order to obtain more descriptive and detailed information about ICBM sites and missiles

Date	Event
18 Aug 1960	First Corona intelligence image: Mys Shmidta Air Base, U.S.S.R.
Aug 1960	The U.S. National Security Council approves the establishment of the National Reconnaissance Office (NRO)
Oct 1960	Soviet Premier Nikita Khrushchev visits the U.S. and warns that the Soviet Union is "manufacturing missiles like sausages"
12 Apr 1961	The Soviet Union successfully launches Vostok 1—Yuri Gagarin becomes the first human in space and first to orbit the Earth; launched from Tyuratam on a Korolev R-7 booster
June 1961	Jupiter IRBM deployment in Turkey begins—missiles within striking distance of Moscow
28 July 1961	Khrushchev orders the acceleration of the construction of hardened silos for missiles
16–29 Oct 1962	Cuban Missile Crisis. The U.S. blockades Cuba for 13 days; ensuing compromise entails U.S. secretly removing deployed IRBMs from Turkey
Aug 1963	U.S.–U.S.S.R. establish "hotline"
5 Aug 1963	U.S. President Kennedy and Soviet Premier Nikita Khrushchev sign the Limited Nuclear Test Ban Treaty
26 May 1972	In Moscow, U.S. President Richard Nixon and Soviet General Secretary Brezhnev initial the Strategic Arms Limitation Treaty (SALT I)
1980s	Moscow begins ambitious strategic modernization program entailing deployment of multiple independently targeted reentry vehicles (MIRVs)—not constrained by the SALT Treaty

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

Robert A. McDonald, Ph.D. and Patrick Widlake

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.

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.

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.

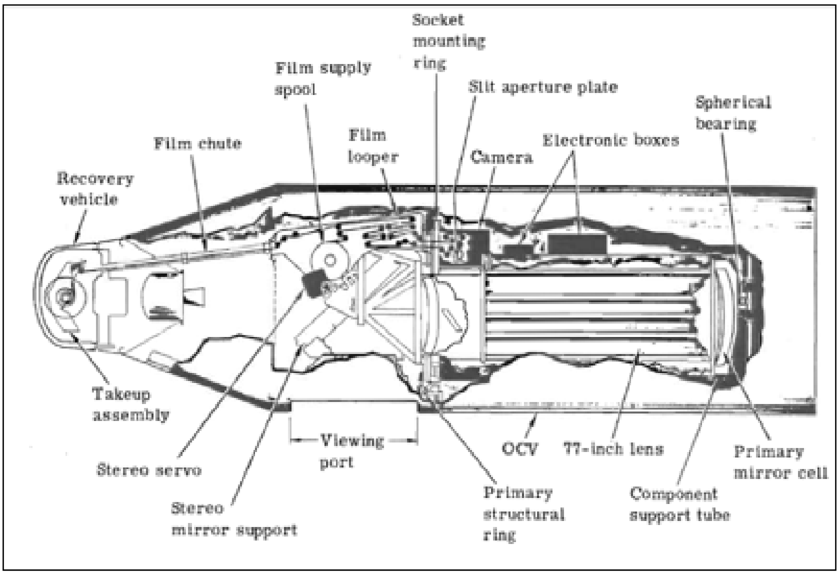

Figure 4. Gambit-1/KH-7 System Diagram
(Reprinted from classified source,CSNR reference collection).

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]

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).

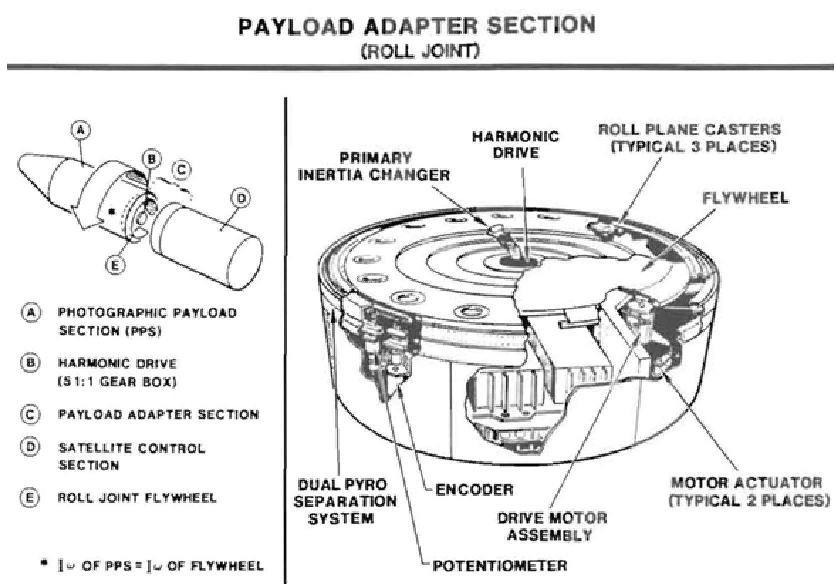

Figure 5. Gambit-3 Roll Joint (Reproduced from Oder, et. al., 1991, p. 57).

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,

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).

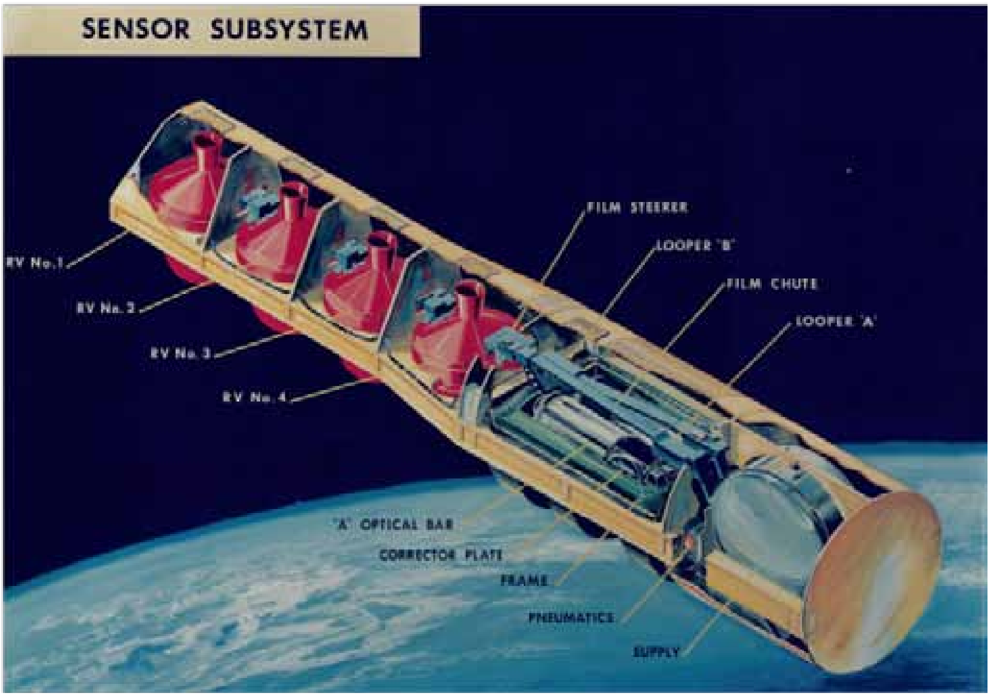

Figure 6. Hexagon Sensor Subsystem.

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).

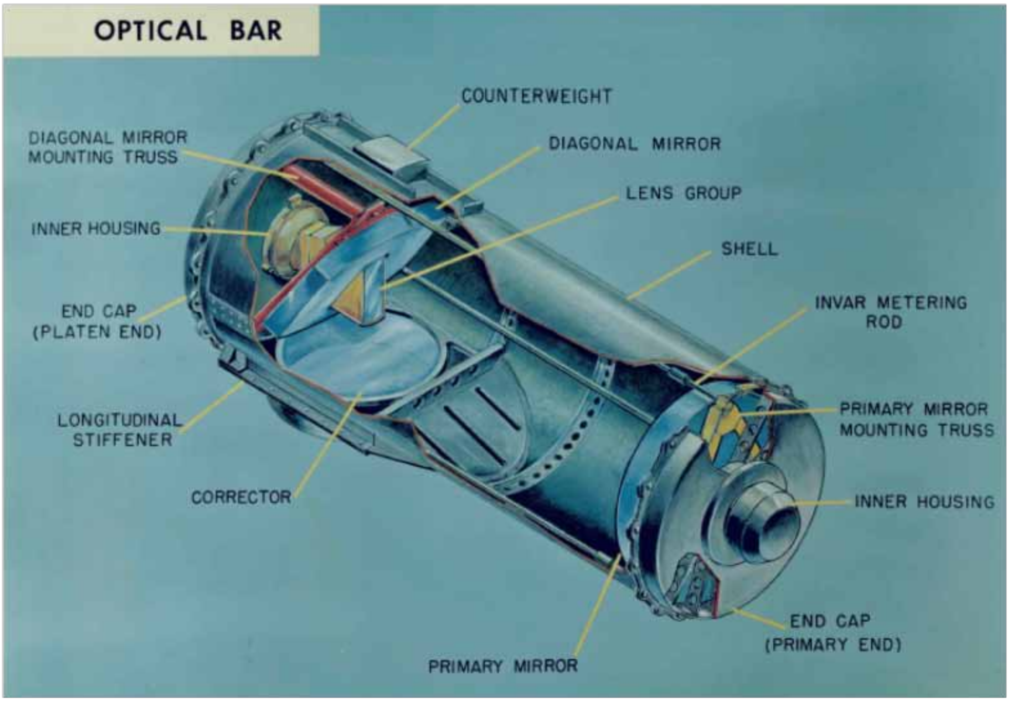

Figure 7. Hexagon Optical Bar.

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

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

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]

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).

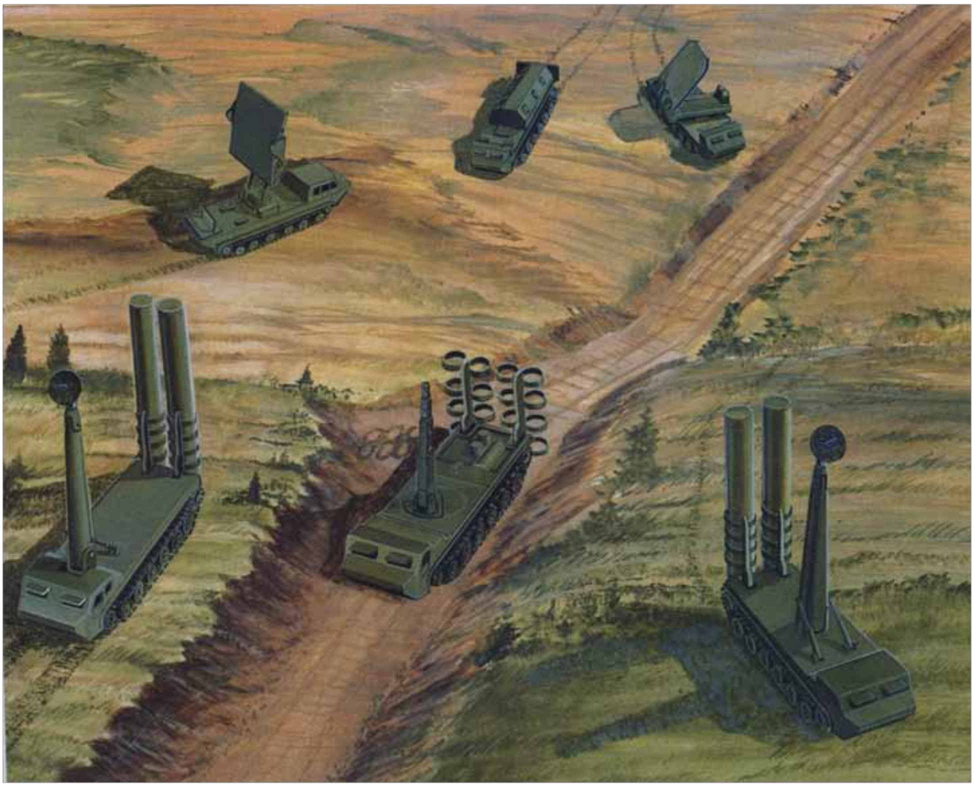

Figure 9. Illustration of Soviet SA-X-12 Air Defense System.

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).

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).

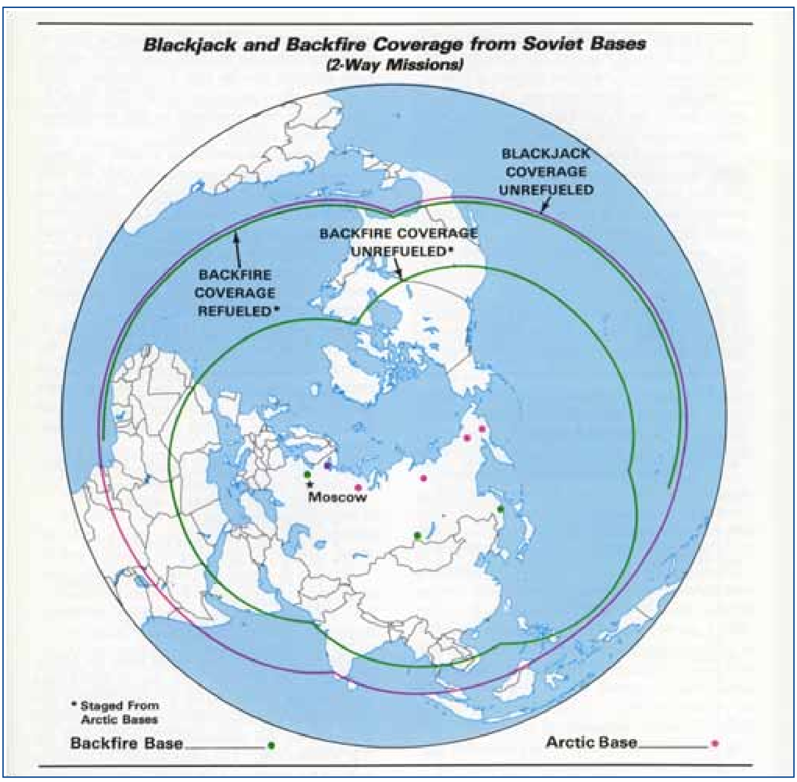

Figure 10. Range of Soviet Strategic Bombers, Blackjack and Backfire.

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

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.

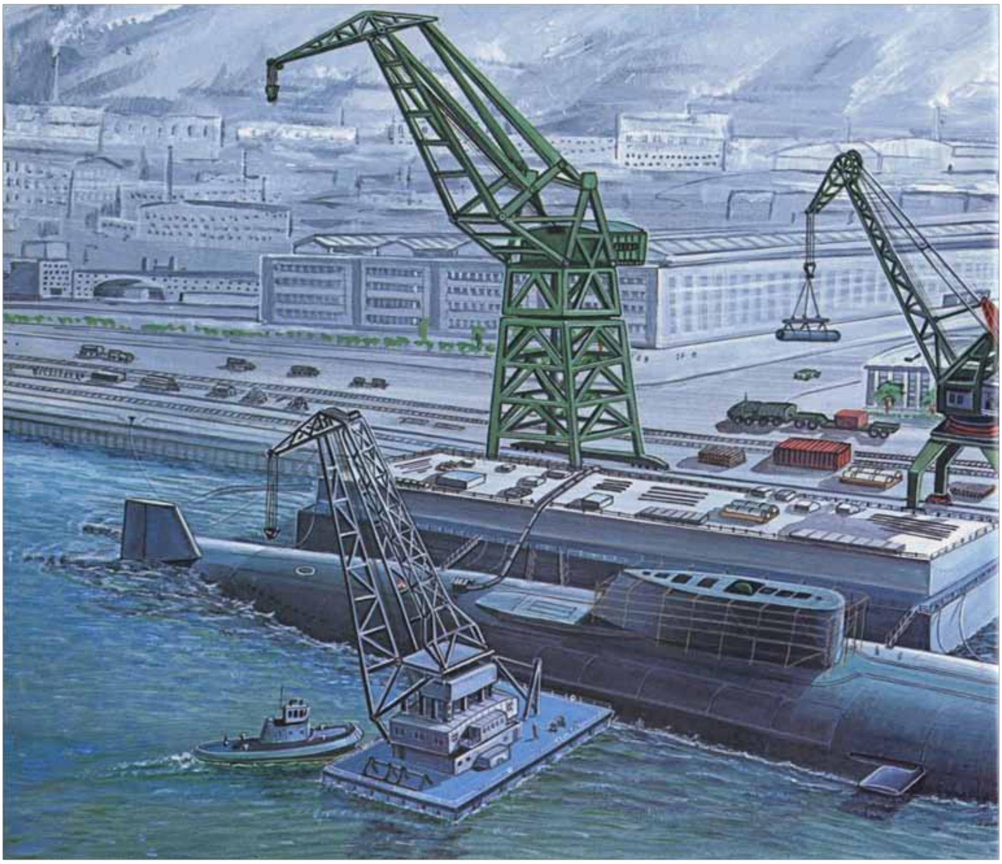

Figure 12. Illustration of Soviet Oscar-class Nuclear-powered Attack Submarine at Severodvinsk Shipyard.

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).

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

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

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]

Gambit-3: Engineering an Innovative High-Resolution Reconnaissance Satellite—*Program Management from the Lockheed Missile and Space Company's Perspective*

Pete Ragusa

Editor's Note: The National Reconnaissance Office (NRO) developed and operated the high-resolution Gambit imagery satellite for 21 years, 1963–1984. Gambit provided detailed, high-acuity pictures of priority intelligence targets that Intelligence Community (IC) photo interpreters exploited for scientific and technical analysis of Soviet and Chinese weapons and facilities. The NRO's Program Office A, also known as the Office of the Secretary of the Air Force for Special Projects (SAFSP), with its contractor workforce, produced two versions of the Gambit satellite, known as Gambit-1 and Gambit-3 (Gambit "cubed"). Compared with its Gambit-1 predecessor, the Gambit-3 satellite featured a significantly more powerful optical payload, the KH-8 camera system, and marked improvements to the satellite control system.

The Lockheed Missiles and Space Company (LMSC) developed the Gambit-3 satellite control system. Lockheed made three critical innovations for Gambit-3: first, the company modified its highly successful and versatile Agena-D spacecraft to incorporate a roll-joint flywheel that increased targeting at slant ranges; second, Lockheed integrated a secondary propulsion system that allowed for complete utilization of the Titan-III launch vehicle's throw weight and fuel, thereby gaining residual fuel in the Agena itself to facilitate operation at lower altitudes and greatly increase orbital lifespan; and third, Lockheed developed the adaptive bias that integrated the roll joint, momentum compensation, and attitude control to yield essentially zero vehicle body rates, which resulted in improved image motion compensation and highest quality resolution imagery. The resulting Gambit-3 satellite control system provided a more stable satellite imaging platform that increased target acquisition and extended operational life, and enabled the satellite to realize the full benefits of its more powerful optics and fast, fine-grain film.

The enhanced Gambit-3 flew 50 successful operational missions between July 1966 and August 1984, capturing the sharpest, highest resolution satellite imagery of its time. Working with the Hexagon search satellites, Gambit-3 provided a principal means for detecting and monitoring Soviet weapons development and deployment, and in conjunction with other national reconnaissance systems, assisted in verifying arms-control treaties.

Author Pete Ragusa was a Chief Systems Engineer and Program Manager on the Lockheed Program Office team. In this article, Ragusa relates how the Lockheed team integrated the roll joint, attitude control and secondary propulsion to operate with the more powerful optical payload and implemented "factory-to-pad" systems engineering processes to ensure each Gambit-3 satellite met all cost and schedule milestones and received rigorous testing to maximize the probability of a successful launch and mission operation.

Engineering a High-Resolution Satellite for the Technical Intelligence Mission

As the National Reconnaissance Office ushered in the era of high-resolution satellite imagery with the July 1963 successful launch of the Gambit-1 satellite, it began to study how to improve the capability. This was the genesis of the Gambit-3[1] development program. The Eastman Kodak Company had developed the optics for Gambit-1's KH-7 camera system, capable of resolution of two feet, and it now proposed to improve the photographic resolution even further. Concurrent with the Gambit-1 development, Kodak had been studying the use of space reconnaissance optics with even larger aperture and focal length than those in the KH-7. Kodak presented its findings, first to Dr. Brockway McMillan, Director of the National Reconnaissance Office (DNRO) and Undersecretary of the Air Force, and then to Brigadier General Robert Greer, Director of the Office of the Secretary of the Air Force for Special Projects, (SAFSP), known in compartmented channels as NRO Program A. Integral to Eastman Kodak's proposal for, though not a part of, the Gambit-3 optical payload—what became the KH-8 camera system—was the inclusion of a roll joint that would rotate the camera in-flight, permitting photography to the left and right of the satellite's ground track. The Lockheed Missiles and Space Company (LMSC) had originally developed the roll joint for an earlier, short-lived, high-resolution satellite known as Lanyard. For Gambit-3, Lockheed proposed to modify its Agena-D spacecraft and integrate the roll joint. After the NRO awarded Eastman Kodak the optical payload contract and then awarded the satellite platform contract to LMSC in May 1964, the Gambit-3 program got under way (Oder, Fitzpatrick, & Worthman, 1991).

The Need for Gambit-3

The Gambit-1 was an excellent program. Its KH-7 camera system featured a 19.5-inch aperture with f/3 lens and effective focal length of 77 inches. This delivered 104 line pairs/millimeter (lp/mm) at a contrast ratio of 2:1, yielding resolution better than three feet ground resolved distance (GRD).[2] This capability gave the Intelligence Community (IC) a collection platform for compiling scientific and technical intelligence on weapons and facilities in denied areas of the Sino-Soviet bloc (Oder, et. al., 1991).

The Gambit-1 satellite was ideally suited for nadir[3] photography, but for off-axis target acquisition it relied on steering the entire spacecraft, the General Electric (GE)-developed Orbital Control Vehicle (OCV), to reposition the camera. The GE OCV space vehicle was approximately 15 feet long and 5 feet in diameter. It possessed good design features: it was capable of +/- 45 degree roll maneuvers for camera swath-width access with slew rates up to three degrees per second. The system could compensate for image motion up to slant ranges of 127 nautical miles (nm) (Oder, et. al., 1991).

1 **Editorial Note:** There was no Gambit-2; in preparing its optical study findings, Eastman Kodak had presented three different options for an improved Gambit camera system, Gambit-2, Gambit-3, and Gambit-4. The variables for each option were optical, related to the focal length and aperture, and increasing either or both increased cost and extended the development schedule. The NRO selected Gambit-3 as giving the desired imagery resolution improvement at an acceptable cost and development time (Oder, et. al., 1991).

2 Resolution is given 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).

3 Photography taken when the satellite is directly over its target.

The drawback with the OCV was its reliability. Of the initial 14 Gambit-1 flights, covering the first two years of program operations (1963–1964), there were five unqualified failures and several other missions with only limited success. Most of the unsuccessful missions experienced OCV programmer and attitude control failures. The OCV's primary design and hardware limitation was the way it performed roll maneuvers: each maneuver expended attitude control gas and imposed lengthy settling times. Because the OCV's reliability was not ideal in the early missions, the maneuvers too frequently resulted in excessive loss of attitude control gas, which limited the satellite's lifespan and reduced the number of targets acquired.

The GE engineers eventually took corrective action and achieved major improvement in OCV reliability that resulted in 13 successes in the final 14 Gambit-1 missions. The GE improvements mostly came after Brigadier General John L. Martin—who had succeeded Greer as Program A director upon the former's retirement—restructured incentive contracting to de-emphasize bonuses for delivering satellites under the projected cost. The SAFSP leadership realized with Gambit-1 that the parallel between aircraft and spacecraft development, as it related to flight testing and cost incentive contracting, was false. Aircraft went through extensive flight test programs, and modifications could be made in the hangars based upon test results, but such was not the case for satellites. Nevertheless, the contracting mechanisms of the time allowed contractors to earn bonuses for delivering satellites under cost, without consideration given to the eventual on-orbit performance. This cost incentive system implied to contractors that any cost-saving measures, even a de-emphasis on quality control and testing, could increase the incentive award. Martin's changes to contract incentives resulted in new GE program management that instituted detailed subsystem and box testing programs, and encouraged managers to become involved at the engineering, testing, and manufacturing levels (Oder, et. al, 1991).

Their experience with Gambit-1 persuaded then-Colonel William King, the Gambit Project Director for Program A, and Martin, then-NRO Staff Director,[4] that significant improvements in both target access and image motion compensation would be needed for the follow-on system, and the SAFSP awarded the Gambit-3 contract to Lockheed's proposed modified Agena-D with roll-joint system on expectations of improved performance and lower development risk compared to the complex GE OCV technology (Oder, et. al., 1991).

Gambit-3 Program Development

Assembling the Program Office. After the contract award, LMSC rapidly fielded a strong Program Office team, following the management style that had succeeded on the Corona program. The company's management philosophy was to organize project-specific program offices complete with program controls, systems engineering, and design and test engineering teams. The Gambit-3 team included Hal Huntley as Program Manager; Robert M. Powell, Chief System Engineer (CSE); Robert Kueper, Program Controls;

4 **Editorial Note:** BGen Martin was NRO Staff Director before serving one year as Vice Director of SAFSP prior to succeeding Greer. King, too, would become SAFSP/Program A director, succeeding Martin.

John Harley, Program Engineer Manager; Don Feak, Payload Adapter Section (i.e., the roll joint) development and integration; and Pete Ragusa, CSE staff and later CSE and Program Manager. The LMSC also developed the optics barrel as a subcontractor to the optics system developer, Eastman Kodak. The entire Program Team reported directly to Jim Plummer, the Space Systems Division Assistant General Manager. Following its practice on the Corona program, Lockheed built the Gambit-3 program around a dedicated project team. All of the program office team stayed with the program through Block I, and if the team needed specialists, it drafted them.

The Gambit-3 development was to be on a very tight, short 24-month schedule. The government awarded the contract in May 1964, and the first launch, Mission 4301, would be on 29 July 1966. It was not until June 1966 that there was confidence in making the July launch.

Key System Engineering Innovations

Integrating a roll joint increased target acquisition at slant ranges. The first key innovation that Lockheed incorporated in Gambit-3 was the roll joint (see Figure 2) that allowed satellite operators to steer only the camera payload—not the entire spacecraft—in roll and achieve more rapid maneuvers with minimum settling times. The roll joint and Agena's proven reliability on Corona and other Air Force space programs was a decisive factor in SAFSP's selection of Lockheed's spacecraft proposal.

As the Gambit-3 program progressed, LMSC re-engineered and upgraded the "standard Agena"/Agena-D[5] with modifications introduced on vehicles 4313, 4321, and 4342. These upgrades greatly increased orbital lifetime and, with the introduction of a command programmer with dynamic control sequences, yielded near-real-time remote targeting for each orbit. Lockheed customized its spacecraft by modifying the forward equipment and aft racks. The forward equipment rack modifications included several new features:

1. Precision attitude controls, which allowed the Agena to perform as a precise and stable tripod for the payload camera;
2. Extended command system, which allowed for improved tracking, telemetry, and commanding functions;
3. Flight batteries and power distribution;
4. A BackUp Stabilization System (BUSS), also called "Lifeboat"; and
5. A small solar array for extended life.

5 The LMSC introduced the Agena-D in 1962, which standardized interfaces, improved component accessibility, and integrated the guidance and power systems of the spacecraft. Both Gambit-1 and Gambit-3 used variants of the Agena-D (Standard Agena) over the life of the programs (Powell, 1997).

The main additions to the Agena's aft rack were as follows:

1. The integration into the main propulsion system of a secondary propulsion system to increase on-orbit lifetime and operate at low altitudes; and

2. "Lifeboat" (BUSS) propellants and controls for emergency recovery, if required.

Adding a secondary propulsion system increased satellite lifespan. The second key innovation Lockheed engineers made on Gambit-3 was integration of a secondary propulsion system that dramatically increased the satellite's orbital lifespan. From the beginning to the end of the Gambit-3 program, the satellite's lifespan increased from five imaging days for M4301 to 126 imaging days on M4353, the next-to-last mission. The secondary propulsion system included smaller thrusters utilizing residual Agena propellant for orbit adjustments that enabled the use of the Titan's throw weight capability and correspondingly reduced the Agena's gross weight. All Agena fuel reserves could then be allocated to maintain the orbit and extend the satellite's life. The addition of solar arrays extended satellite power. The longer lifetime allowed for the planning of more comprehensive missions, for which the program office doubled the film amount, necessitating the inclusion of a second recovery vehicle (RV). The dual RV system, combined with the development and use of ultra-thin base film, allowed the later Gambit-3 satellites to carry 10,000 feet of 9.5-inch wide film for the strip camera and an additional 1,080 feet of 5-inch film for the terrain camera (for mapping).

The overall Gambit-3 satellite configuration is depicted in Figure 1.

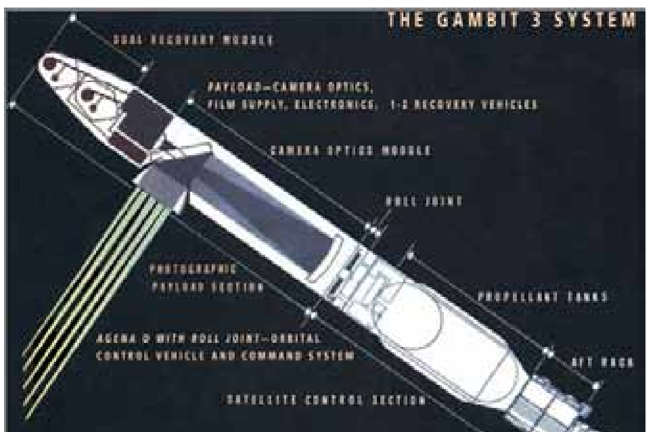

Figure 1. Gambit -3 Satellite Configuration (modified from Oder, et. al., 1991, p. 66).

Adaptive bias reduced attitude and body rate errors to zero. The third, and ultimately pivotal, system engineering innovation for Gambit-3 was the "adaptive bias," a concept this author arrived at in a discussion one day with Thompson-Ramo-Wooldridge's

(TRW's) command software programmer.[6] Without adaptive bias, Gambit-3 could never have achieved the astonishing image resolution that it eventually returned. Although the Block I system featured a very capable Eastman Kodak camera and fast film, and the roll joint allowed for angled photography to both sides of the ground track, the system's image motion compensation was less than optimal. The author reasoned that if the LMSC spacecraft engineers could know the moment of inertia very accurately, they could program the Agena's gas jets to turn off, and let the satellite drift during photography. This integration of the roll joint, momentum compensation, and attitude control yielded essentially zero vehicle body rates, which resulted in improved image motion compensation (less than one-tenth of an hour hand rate and zero settling time). Combined with Eastman Kodak's thin, fine-grain film, the adaptive bias improved Gambit-3's image resolution to better than two feet GRD. The mismatch between the roll joint and optics was accepted without attitude correction. The TRW-developed satellite commanding software—with the algorithms provided by LMSC—compensated for all residual errors; thus, with all targeting errors accounted for, the system reduced "marginal film use" to nothing and effectively increased target acquisition per mission and best resolution.

Having a roll joint with a flywheel further improved image motion compensation by facilitating the steering of the payload as the satellite vehicle rolled. This resulted in significantly more rapid maneuvers with minimum settling times, increasing priority target access by up to three times as much. The team also reduced compensating control gas expenditure, another key to achieving extended life on orbit. Inefficient control gas expenditure had been the Achilles heel of the Gambit-1 OCV.

Program office instituted rigorous scheduling and control. All the Gambit-3 program scheduling and control was run by the Program Controls operation (Robert Kueper's team). The team established firm schedules and rigorous controls to ensure milestones were met for testing, builds, and component integration. Their management control extended to the following areas:

1. Engineering releases;
2. Procurement,
3. Manufacturing builds,
4. Detailed component and box testing,
5. Integrated satellite builds,
6. Integrated environmental satellite testing and
7. Integration of satellite and payload at the launchpad.

6 **Editorial Note:** The story of this serendipitous conversation and the eventual implementation of adaptive bias is, unfortunately, outside the scope of this article. Nevertheless, it makes for a wonderful example of how great innovations were often arrived at in the early NRO: through brainstorming and collaborative idea-sharing between contractors and government managers working to a common goal--in this case, Lockheed engineers collaborating with TRW software and Kodak optical payload developers to calculate and correct for pitch, yaw, and roll offset errors. *National Reconnaissance: Journal of the Discipline and Practice* hopes to be able to fully recount this story in a future edition.

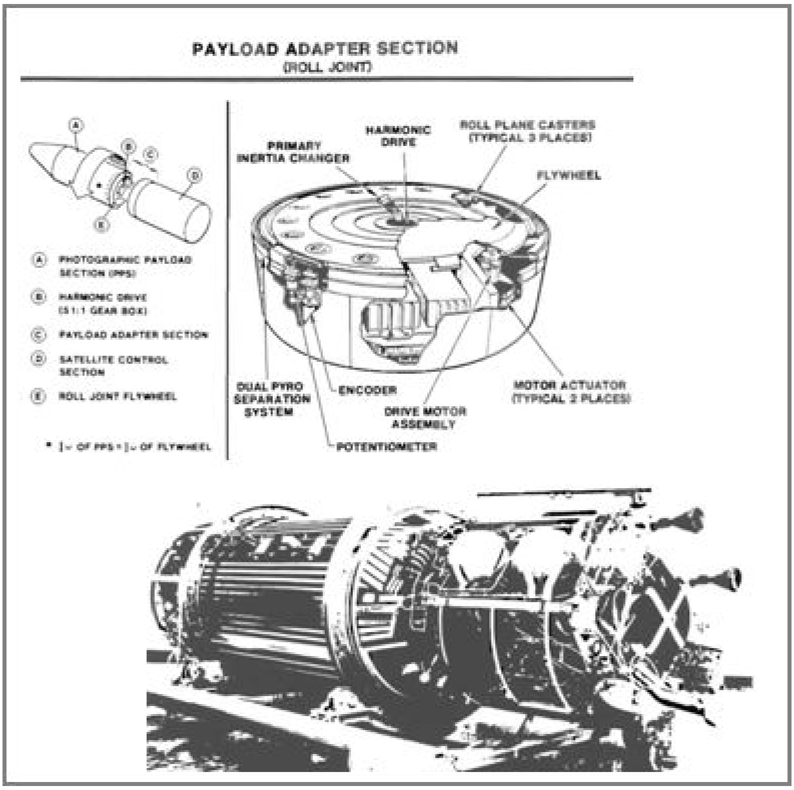

Figure 2. Gambit-3 Roll Joint and Aft Section of Spacecraft (reprinted from Oder, et. al., 1991, p. 57 and 82).

The Program Office delineated milestones down to all components at each supplier and facility. It assigned expeditors to the factory floors in LMSC and major subcontractors. The office used every resource on schedule-critical items to achieve an "on time" successful first launch, which the team accomplished in 26 months from contract go-ahead.

Lessons from Corona: the "factory to pad" concept, reducing cost and schedule. Lockheed's final key systems engineering innovation, one that reflected LMSC program management philosophy, was the factory-to-launchpad concept. This concept grew out of the experiences and lessons learned with the Corona development. The concept entailed fully testing system components at the factories, to include the modified Agena at LMSC and the optical payload at Eastman Kodak, before shipping them independently to the launch site. As the system integrator, LMSC performed all payload mass property measurements at Kodak, which were critical for roll joint and attitude control settings needed for the mission target commanding software. This process also assured seamless mating of the spacecraft and payload.

The Gambit-3 program was the first to introduce complete environmental testing. Lockheed engineers performed qualification- and acceptance-level environmental testing on all individual hardware, which was both vibrated and thermal vacuum tested. The testing also included integrated command-system-driven, end-to-end test sequences called "Programmed Integrated Acceptance Tests" or PIAT. The LMSC engineers ran the PIAT at each environmental test phase and repeated the testing at the launch base. The final PIATs verified that all interfaces between the satellite control section and the payload were sound (Oder, et. al., 1991).

The factory-to-launchpad assembly and testing process (Figure 3) ensured that both spacecraft and payload arrived flight ready at Vandenberg and eliminated the need for integrated testing in the auxiliary launch complex. The satellite control section, followed by the payload, was mounted directly onto the Titan-IIIB launch vehicle, without having to spend additional time in the missile assembly building, as prior programs had done. All Gambit-3 missions followed this process. The Gambit-3's extended lifetime reliability achievements can be attributed to the factory-to-launchpad process.

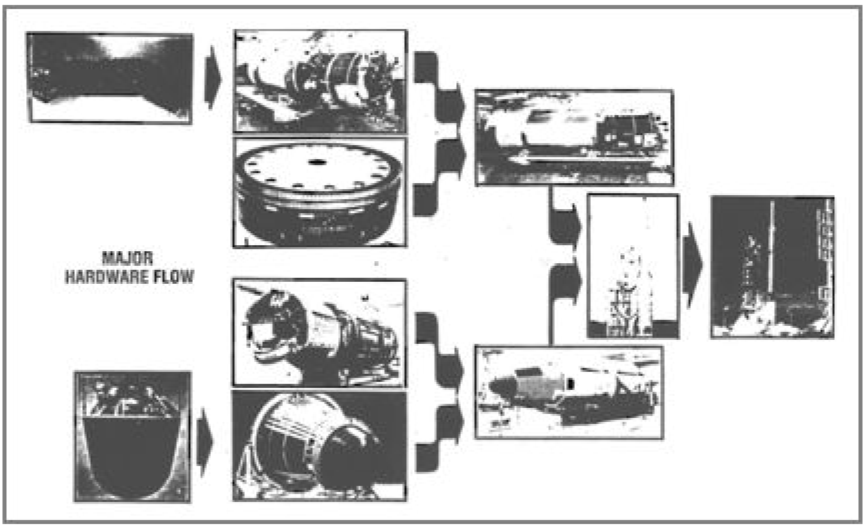

Figure 3. Gambit Program Major Hardware Flow (reprinted from Oder, et. al., 1991, p. 73).

Gambit-3 Mission Results

The Gambit-3 satellite surpassed Gambit-1's capabilities in every respect and it gave the IC a reliable collector of technical intelligence for 18 years (1966 – 1984). It exceeded performance expectations for resolution, satellite duration, and target acquisition. From the earliest Gambit-3 missions, the level of detail in its imagery allowed photo interpreters to identify, by model, the armor and artillery introduced into Soviet military service. They could also assess the extent of Soviet deception and camouflage techniques. By the end of the program, the resolution had gotten so good that the exact number remains sensitive and cannot be revealed. Of considerable importance was Gambit-3's ability to satisfy high-priority mensuration requirements.

Regarding satellite duration, the early Gambit-3 flights lasted approximately one week; by the end of the program, missions lasted up to four months. Total coverage and target acquisition also increased throughout the program. The early flights acquired some 2,000 photographic frames, which grew to 6,000 frames by the 23rd mission (the first using two RVs), 10,000 by M4341, and 27,652 frames, capturing 49,372 intelligence targets, by the penultimate M4353 (Oder, et. al., 1991).

Outlook: Applying Corona Lessons in Conjunction with Innovation in Engineering and Program Management

The program enjoyed tremendous success, in large part, because it embraced innovation in program management and systems engineering. The Lockheed factory-to-pad concept first employed on the Corona program and the adaptive bias engineered to overcome the inherent limitations in the Gambit-1 OCV were just two of many innovations introduced on Gambit-3. The LMSC's systems engineering approach conceptualized and integrated all program elements, including the distinct spacecraft subsystems, camera optics, film, and ground command and control. The program office learned many lessons that were applied to later programs. Among those lessons, the following stand out as the key elements for program success:

1. A challenging program needs a "can do" spirit; this can be instilled through a strong statement of need and a joint commitment of the contractor and government customer;
2. A program increases its chances of success if it can select key team members and keep the team together throughout the entire development (continuity is key);
3. The team needs to apply a rigorous, top-down systems engineering process; and,
4. To meet cost and schedule milestones, the team needs strong program controls and project expeditors.

To all of this, one must add that the skills and dedication of every individual on the program team were essential for success. This includes the government program managers and all the principal contractors: LMSC, who developed the satellite control system; Eastman Kodak, who developed the photographic payload section; Martin-Marietta, who built the Titan-IIIB launch vehicles; and General Electric, who manufactured the recovery vehicles and developed the command subsystem.

Pete Ragusa was Lockheed's Chief Systems Engineer (CSE) and Deputy Program Manager of the Gambit program, a highly evolutionary program in which the performance and payload capabilities improved significantly with each block of satellites. Mr. Ragusa first joined Lockheed Missiles and Space Company as a test engineer in Sunnyvale, California in July 1960. He next moved into Guidance and Control Systems Design, where he developed precision payload pointing and attitude control systems. In 1969, he directed and won a competitive proposal for the first Department of Defense Space Shuttle application. He retired in 2001 after serving as Chief Engineer for the Milstar program.

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Hexagon— "No Single Failure Shall Abort the Mission" —*Managing System Integration for the NRO's Wide-Area Search Satellite from the Lockheed Missile and Space Company's Perspective*

Sam Araki and Steve Treat

Editor's Note: Under U.S. Government program management, a select industry team designed, developed, and successfully launched the first Hexagon imaging satellite 47 months after program initiation. That first Hexagon satellite, Mission 1201, delivered some 40,000 linear feet of film in its first of three recovered film "buckets" to the National Photographic Interpretation Center (NPIC), containing wide-area, stereoscopic imagery of high-priority intelligence targets in the Soviet Union and China. It would be only the beginning of an ever-increasing volume of film imagery that the state-of-the-art Hexagon satellite delivered. A highly complex design of many moving parts, Hexagon nevertheless proved to be very robust and reliable over 13 years and 19 successful operational missions that provided invaluable foreign intelligence and geodetic data for mapmaking and collectively exceeded all search and surveillance and mapping mission objectives set forth at program start.

The U.S. Intelligence Community (IC) used Hexagon imagery to locate key targets for the National Reconnaissance Office's high-resolution satellite, Gambit-3, to subsequently photograph and gather further technical details. Perhaps most importantly, Hexagon imagery provided the "technical means" foundational data for verifying Soviet compliance with arms control treaties.

The co-authors, Sam Araki and Steve Treat, were engineers at Lockheed Missiles and Space Company (LMSC) and worked on the Hexagon program. They provide us with a first-hand perspective. They took the title for this article from LMSC's design philosophy that "no single-point failure shall abort the mission." As Oder, Fitzpatrick, & Worthman (1992) explained with an example, "no single-point failure" meant that wires carrying signals from two redundant black boxes had to be in two separate cables with separate routings and grounding points.

Given the ambitiousness of the Hexagon design and the nominal difficulties of reconnaissance satellite development, the Hexagon program is a real success story, though that could not have been predicted confidently at the program's beginning. The Hexagon program got off to a very rocky start. There were competing programs, the most significant called Fulcrum and S-2, with each having different designs for the camera, film supply, film transport, and even recovery system. Even after defining one set of requirements and a unified system design to meet them, the NRO divided overall management between two program offices, and it awarded the contracts for the different system components months apart from each other, causing integration problems. The Hexagon program exceeded its projected cost and schedule and faced possible cancellation on multiple occasions.

How then did Hexagon eventually succeed? There were multiple factors, not the least of which was the fact that, despite having obstacles to overcome, Hexagon benefitted from having a strong statement of system need and a total commitment from government and contractors alike. The Lockheed Missiles and Space Company (LMSC), as overall system integrator, was instrumental in ensuring all system interfaces connected and worked together and that the program applied proven top-down system engineering processes. Other key factors for program success included the institution of a parts monitoring program (see the "Monitored Line Program" below) that ensured the program received the best quality parts, the implementation of a factory-to-pad concept for satellite vehicle assembly and testing, and, critical to the system's capability to tolerate most on-orbit failures, the adoption of a design philosophy of "no single failure shall abort the mission" (Oder, et. al., 1992, p. 76).

The Hexagon program succeeded, in part, because of rigorous program management that emphasized top-down system engineering with strong program controls to meet cost and schedule milestones and performance requirements. The program office instituted a testing philosophy that ensured, as much as possible, that a flight-ready satellite would be delivered to the launch base. Finally, the industry team built Hexagon to a system design with multiple functional redundancies to prevent the failure of any single component from causing the entire mission to fail, short of a complete camera failure, for which redundancy could not be built (Oder, et. al., 1992).

The story of LMSC's role as the overall system integrator for the Hexagon development program began as the IC was formulating the requirements for a new search and surveillance satellite for which satellite contractors were offered the opportunity to prepare unsolicited proposals.

Figure 1. Sequence of a Hexagon Satellite Launch

The Hexagon Requirements

By mid-1964, the Corona photoreconnaissance satellite, the world's first imagery satellite, had become more reliable, but was reaching its performance limits. For the wide-area search and surveillance intelligence and mapping missions, the IC needed a more capable replacement for Corona. About 1965, the National Reconnaissance Office (NRO) offered satellite contractors the opportunity to prepare unsolicited proposals to adapt advanced technology to produce a system design that met the latest intelligence requirements. The NRO, in effect, challenged the space industry team to develop a brand new satellite with ten times the capability and launch it in three years. The technology available then, mid-1960s vintage, is of course obsolete today, but at the time Hexagon was to be the next generation of Corona and would be for its time the most mechanically complex satellite, incorporating the latest state-of-the-art (i.e., first generation) semiconductors (transistor discrete devices and hybrids) and processors (see Figure 2). The Lockheed team conducted a company-funded system concept study and prepared an unsolicited proposal which incorporated all of its system engineering and program management lessons learned from building Corona. By April 1966, the competing programs and designs had been resolved, and the Director of the NRO (DNRO) Alexander Flax issued his management directive, "Systems Operational Requirements for the New Search and Surveillance System." The new system was to provide:

1. "...an optimum capability for fulfilling the search and surveillance objectives specified for the time-period beginning in 1969...";
2. "Systematic search of some 12 million square nm...semiannually";
3. "Periodic surveillance...of previously known specific objective targets at a ground resolution sufficient to detect and analyze changes in status or capability of a target";
4. "Numerically, coverage approaching a total of 5,000 specific targets....with coverages of various numbers required at two months, quarterly ...";
5. "During periods of crisis...coverage of any selected area...to prove effective...must be flexible, i.e. capable of prolonged standby prior to launching, rapid response after decision to launch...In addition, the overall system must be designed for minimal time between launching, recovery, and delivery of photography to the user"; and
6. "...ground resolution from perigee altitude 2.7 ft. or better, at nadir" (Oder, et. al., 1992, p. 65).

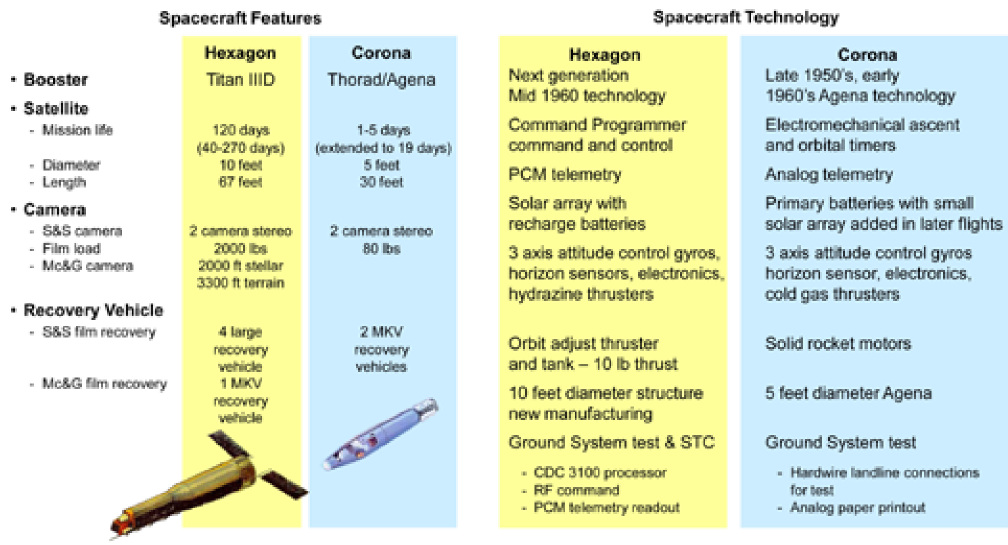


Figure 2. Hexagon–Corona Comparison (Graphic Courtesy of Lockheed-Martin Corp.)

Satellite Configuration and Contractors

An industry team built Hexagon to meet the requirements, which resulted in the nearly 30,000-lb, 10-ft in diameter, and 59 ft-long Hexagon satellite (without shroud) shown in Figures 3 and 4. The industry team consisted of: (1) LMSC, the satellite builder and system integrator; (2) Perkin Elmer (PE), the builder of the two panoramic cameras with Eastman Kodak (EK) film; (3) McDonnell-Douglas, the builder of the four large recovery vehicles (RVs); (4) ITEK, the builder of the mapping camera subsystem (MCS); and, (5) General Electric, the builder of the mapping camera film RV (called the Mark V, it was very similar to Corona and Gambit satellites' RVs). The Government program management was a joint Air Force/Central Intelligence Agency (CIA) effort. Colonel Frank S. Buzard (U.S. Air Force) of the Office of the Secretary of the Air Force for Special Projects (SAFSP or NRO Program A) contracted with LMSC, McDonnell-Douglas, ITEK Corporation, and General Electric, and the Aerospace Corporation provided Systems Engineering and Technical Analysis (SETA) support. Donald W. Patterson of the Central Intelligence Agency's (CIA's) Office of Special Programs (OSP or NRO Program B), awarded and oversaw the PE contract, with Thompson-Ramo-Wooldridge (TRW) providing SETA. Both SAFSP (Program A) and CIA/OSP (Program B) reported to the DNRO.

Following the LMSC management philosophy that had proven to be successful on Corona and Gambit-3, LMSC established a project-specific Hexagon office that reported directly to Dr. Fritz Oder, Space Systems Division General Manager. The Hexagon Program Office comprised the Program Manager (first, Stan Weiss, then Paul Heran), Program Controls (Jack Chapman), Chief Systems Engineer (authors Sam Araki and Steve Treat at different times in the project lifecycle), Engineering (Ray Benton, then Ken Connestra), Payload Integration Management (Bert Bulkin), Test Operations Management (Pat Milcaire), Manufacturing Manager (Dave Owen), and (test and integration) Building

Construction Manager (Ray Bell). All of the initial program team stayed with the program through completion of the first flight.

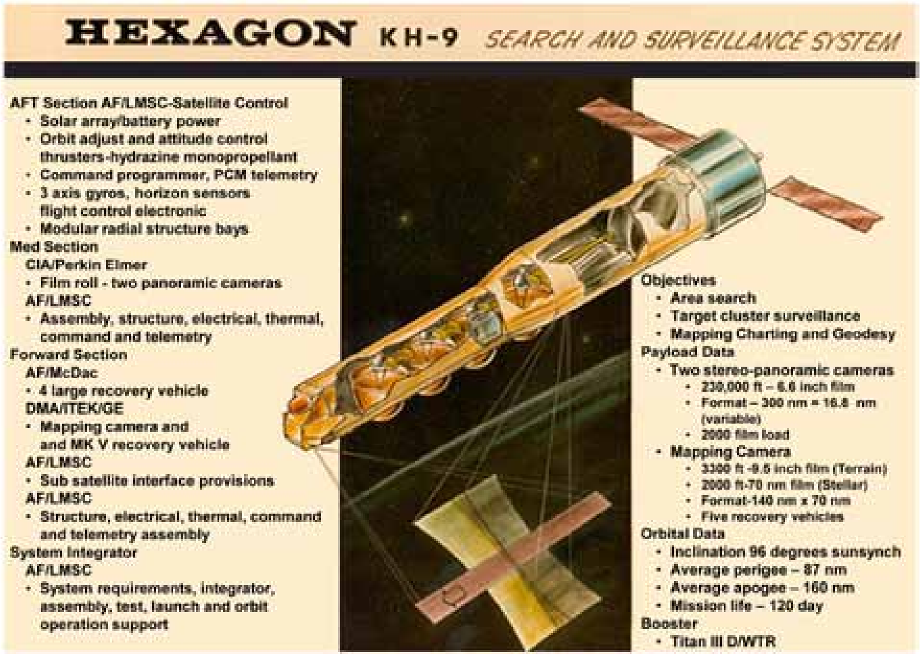


Figure 3. Hexagon (Graphic Courtesy of The Lockheed-Martin Corporation)

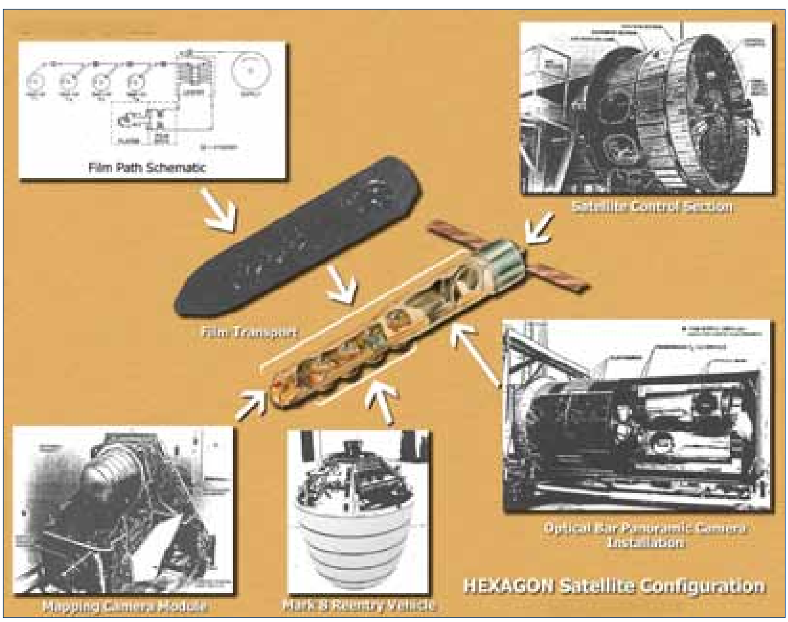


Figure 4. Hexagon Satellite Configuration
(Figures 3 and 4 compiled from separate figures in Oder, et. al., 1992).

The contractor team developed and configured the Hexagon satellite and its subsystems to provide complete stereo coverage of the Soviet-Sino bloc denied area with a ground resolution of 2.7 feet at perigee altitude. The sensor subsystem consisted of two camera assemblies, a film supply, and four film take-ups. The optical system was mounted in optical bars that rotated continuously during photography to provide cross-track scanning. Reciprocating platens in the optical bars directed the film across the focal plane at velocities up to 200 in/sec. The film then wound its way to the foremost RV where it was taken up, a film path distance from supply to RV-1 of 140 feet. Film was recovered by the four large RVs in increments over the mission life. The original mission design life was 30 to 50 days. By increasing the amount and improving the quality of expendables (film, propellant, batteries) and by designing and engineering extensive redundancy and other features into the satellite vehicle (SV), the satellite engineers achieved an SV with a much longer life on orbit and the capability to continue successful operations after equipment failures (Oder, et. al., 1992).

The "Rocky Start"

Arriving at the optimal configuration and ensuring that all system and subsystem components were properly integrated proved to be a difficult challenge. The source selection committee partly contributed to the difficulties by staggering the awarding of contracts for different satellite components (see Figure 5, "Source Selection Schedule"). Just as importantly, the NRO's decision to divide management responsibilities for the different contractors between NRO Program A and Program B, not to mention the tight development schedule that originally called for a first launch by 1969, resulted in development contractors beginning work on their assigned system component immediately upon contract award, before an overall system configuration had even been decided upon and without common understanding of how the hardware would be assembled, tested, and launched.

Source Selection Schedule				
Part of System	RFP Proposal Issued	Proposal Due	Brief DNRO on Evaluation	Actual Decision Date
Sensor Subsystem	23 May 1966	27 Jul 1966	01 Sep 1966	Oct 1966
Satellite Basic Assembly (SBA)	16 Jun 1966	22 Aug 1966	26 Sep 1966	Jul 1967
Recovery Vehicle (RV)	19 Jul 1966		20 Oct 1966	May 1968
Stellar Index Camera	24 Aug 1966	17 Oct 1966	4 Nov 1966	May 1968

Figure 5. Hexagon Source Selection Schedule (reproduced from Oder, et. al., 1992)

As Figure 5 indicates, the LMSC submitted its proposal in August 1966, and the NRO/SAFSP announced it as the satellite basic assembly contractor in July 1967. However, the NRO/OSP had announced Perkin Elmer as the sensor subsystem contractor nine months earlier, in October 1966. Shortly after contract go-ahead in July 1967, LMSC and PE met at the first interface meeting. Given a nine-month lead time, PE had already defined a camera configuration with the film supply in the roll axis feeding the camera and transporting the film into two RVs. The PE engineers likewise assumed they would assemble their camera and the McDonnell-Douglas RV configuration at the PE facility to ship directly to the launchpad. The LMSC SV design, by contrast, required pitch orientation to reduce disturbance, four RVs, and a film path as shown in Figure 4. The company's development approach also included a satellite integrated environmental test program and factory-to-pad concept based on lessons it had learned from experience with the Corona program.

It took another ten months—from July 1967 to May 1968—to resolve these differences. Intense efforts by OSP/PE and SAFSP/LMSC led to convergence in spacecraft/sensor design interfaces and the adoption of factory-to-pad implementation. The four-RV configuration with pitch axis film supply prevailed as shown in Figures 3 and 4.

Top-Down Systems Engineering: Lessons from Corona and Gambit[1]

As the integrating contractor, the LMSC worked with the government and associate contractors to develop a top-down systems engineering process (see Figure 6) derived from lessons learned on the Corona and Gambit programs. Lockheed had responsibility to integrate the plans, schedules, and requirements, and working with all of the associate interfaces, to prepare the interface control documents, and maintain configuration control. During the design phase, the LMSC team conducted interface working group meetings, and at the design release point, the company conducted a system audit with all associate contractors to assure compatibility with requirements. This audit uncovered a number of incompatibilities that, once resolved, built confidence in the system design with the government agencies and contractors. Team building and cooperation was critical because Lockheed had no direct contract authority with the associate contractors.

One of the lessons learned from experience on the Corona program was that conducting system integration and testing at Vandenberg Air Force Base (VAFB) was a mistake: the launch base was the wrong place to experience failures. System tests should be conducted at the factory, and problems fixed at the factory. This experience taught the engineers to move system integration and testing to the factory. The LMSC incorporated the factory-to-pad concept employed on Corona and Gambit (Figure 7 diagrams the process) to ship a completely assembled, system-tested, flight-ready satellite to the launch base and shorten the pre-launch pad time to 14 days.[2] The LMSC built a dedicated system integration, assembly, and test facility, which included developing all of the environmental test chambers.

1 As a systems integrator for Lockheed on all of the early Corona program's missions, author Sam Araki helped analyze problems and take corrective action, efforts that contributed to the first successful recovery of an object from space on Corona Mission 9013. In *National Reconnaissance: Journal of the Discipline and Practice*, Winter 2009/2010, p. 55-68, Araki recounts how these experiences taught Lockheed the value of employing rigorous systems engineering processes and having end-to-end system responsibility.

2 The Corona and Gambit programs began the practice of delivering completely factory-tested payload and vehicle sections to the launchpad for mating and interface checks before launch.

Systems Engineering: A Top-Down and End-to-End System Responsibility

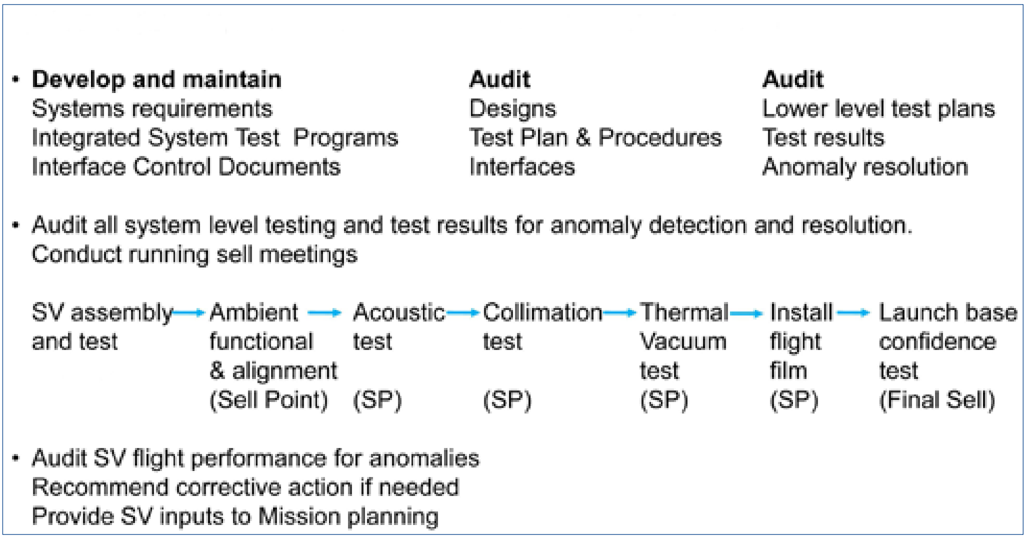


Figure 6. System Engineering Process

The Lockheed engineers incorporated a "running sell" concept. After every system test milestone, they collected all of the anomalies and failures, closed on the corrective actions with all contractors, and obtained government "buy-off." With that accomplished, the "final sell" in the factory and the Launch Readiness Review at the launch base worked like clockwork. Given the team continuity and experience, the flight satellite processing became very stable and efficient. The system requirements remained stable through the life of the program. The satellite performance in orbit met all mission objectives, confirming the effectiveness of factory operations in getting the SVs ready for flight. Pad spans were kept short. No disassembly was ever required.

Another lesson learned from experience with Corona was how to minimize on-orbit equipment failures, such as gyros, electrical junction box shorts, timer malfunction, gas and fluid line fitting leaks, wire harness connector shorts, film roller static discharge, pyro misfires, spin rocket motor unbalance, and battery cell shorts. The Corona program incorporated an independent RV recovery back-up system, "Life Boat," to compensate for what were too frequent failures, but the reliability was still 70–80%. Many of Corona's equipment failures were because of faulty workmanship and a lack of understanding of the space environment, and, all too often, these failures led to mission aborts. Based on this experience, the LMSC adopted for the Hexagon program the following new system requirements:

- Redundancy design features throughout the system except in the sensor subsystem, with the philosophy that no single failure will result in an aborted mission;
- Integrated environmental test program at the parts, components, and system levels;

- Single point ground and EMC [Electromagnetic Compatibility] emission, susceptibility requirements defined, and testing to confirm compliance;
- Radio Frequency (RF) system test with no land lines (i.e., test like we are in orbit);
- Specification performance maintained at low bus voltage; and
- Parts quality improvement by Monitored Line Program and burn-in requirements. (Figure 9)

Satellite orbit operation was rehearsed in both the test facility and the Satellite Test Center (STC), and corrective action teams at the STC worked on identified anomalies in a similar way to how the engineers operated in the factory. This approach really paid off on the first Hexagon flight, which experienced two major anomalies. The booster retro rockets at separation sprayed the satellite power module thermal finish. The on-orbit temperature control of the batteries in the power module had to be nursed for the entire mission. The monopropellant hydrazine thrusters began to use too much propellant, so the usage had to be managed by controlling the on-off cycle carefully. With tender loving care, this satellite operated for 52 days: 31 imaging days and 21 days beyond that, used to develop flight system operating experience and gain additional satellite reliability data. The 52 days exceeded the initial Block I contract, which specified 30 days imaging and a 45-day on-orbit goal to allow for post-imaging system exercises.

Factory-to-Pad Concept Implementation

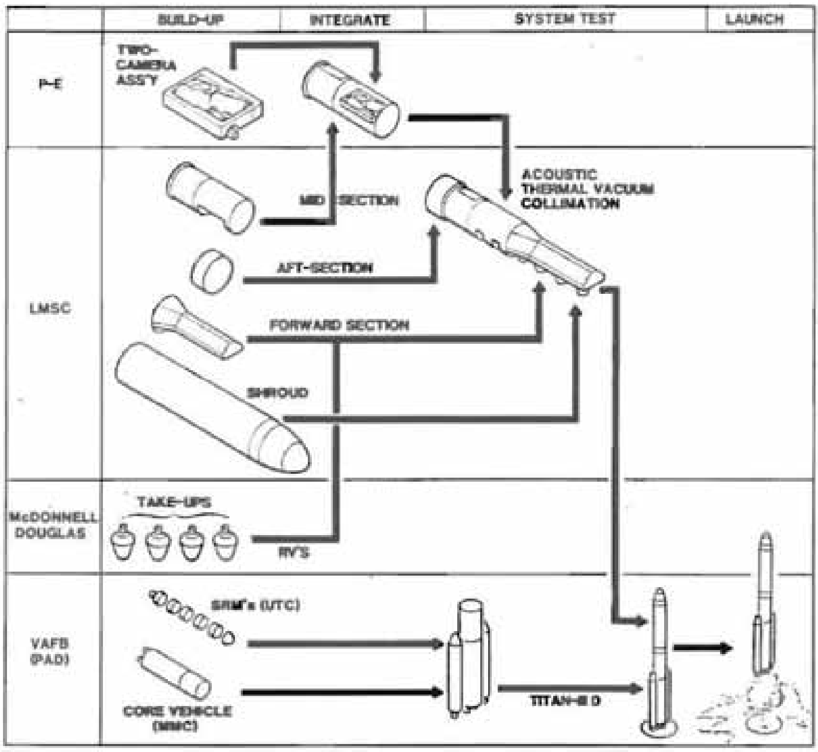
The in-house LMSC studies prepared for the Hexagon proposal cycle had developed a "Satellite Vehicle Assembly and Test Plan" incorporating these elements:

- Complete SV assembly and testing in the factory to ship a launch-ready vehicle to VAFB;
- After SV assembly, test to verify compatibility and system integrity;
- Following that, test the entire assembled satellite vehicle;
- Test satellite basic assembly, sensor subsystem, and RVs end-to-end in simulated mission profiles, including ascent vibration and on-orbit thermal/vacuum environments; and
- During these tests, operate all the subsystems that can be exercised, including camera optical performance tests.

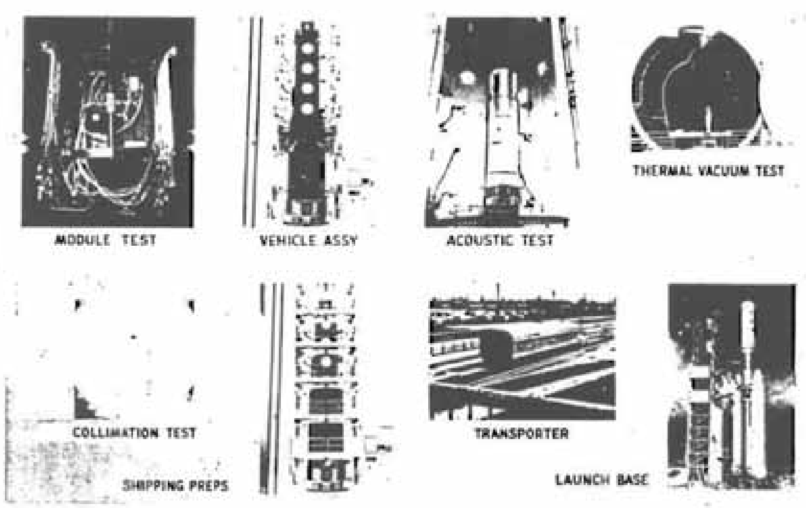
Assembly and thorough environmental testing of a complete flight configuration, 10-foot diameter satellite vehicle required a new factory building. The LMSC developed the requirements and the design features for the building, and for a manufacturing facility that would be needed, and committed in the proposal to build them for the program.

Lockheed built one facility for manufacturing and another for satellite integrating, assembly, and environmental testing. The satellite integration facility was a state-of-the-art, computer-aided complex for simulation, design, manufacturing, assembly, and system environmental test complex.

A Lesson From the Corona Program: The Factory-to-Pad Process



Factory-to-Pad Process



Hardware Flow

Figure 7. Hexagon Factory-to-Pad Process and Satellite Hardware Flow
(reprinted from Oder, et. al. 1992)

The building also provided office and engineering space for all LMSC program people and separate dedicated areas for associate contractor and customer people. There was on site a permanent team from each government agency and associate contractor. The resulting mutual accessibility of all parties helped achieve the rapport essential to a successful development.

As the hardware arrived from the various associate contractors, a permanent vehicle-specific team was formed with representatives from all of the contractors. The customers also assigned members to the permanent team.

The "Factory to Pad System Assembly and Test Program" in Figure 8 reflected LMSC's Corona experience. The assembled flight vehicle, including the shroud, was exposed to an acoustic environment based on the best empirical data available on launch conditions. In orbit configuration, without the shroud, the flight vehicle was exposed to space conditions in the state-of-the-art thermal vacuum chamber. With a programmable quartz lamp array heat source, nitrogen cold wall, and high vacuum capability, the thermal control system for the whole vehicle was verified. The collimation chamber was specialized for sensor system performance verification at vacuum.

The SV testing was conducted end-to-end by RF, using flight instrumentation without breakout boxes and land lines. This testing provided a command and data environment closely simulating flight conditions for the people who would later support flight ops.

Lessons Derived from Corona

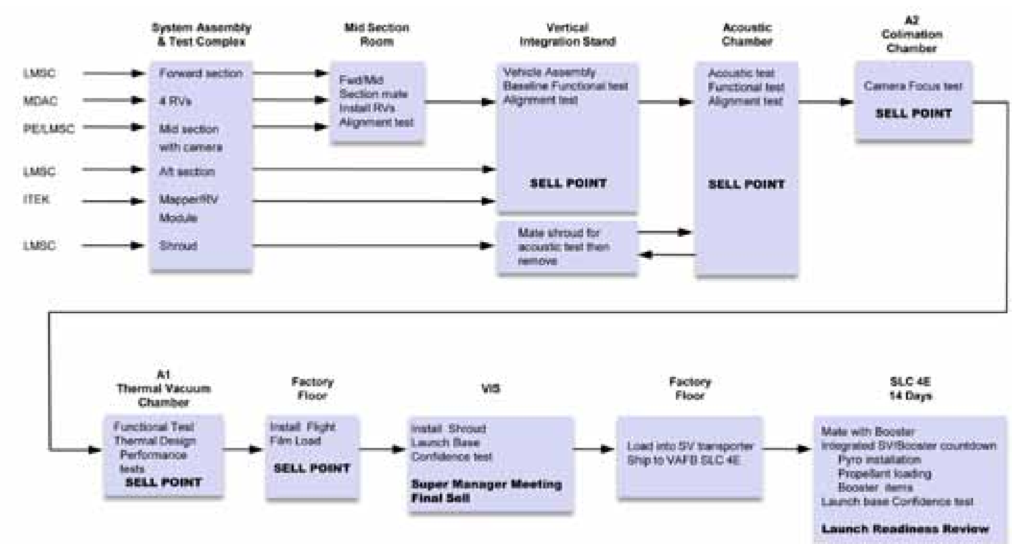


Figure 8. Hexagon Factory-to-Pad System Assembly and Test Program

As the engineering and qualification hardware was built and tested at each of the associate contractors, it was all delivered for installation into the system development vehicle and system qualification vehicle. These vehicles were used in developing the flight system and also to develop, proof, and qualify test station procedures, equipment, software and handling equipment. All assembly stands and the acoustic, thermal-vacuum and collimation chambers and the launch facilities were validated. With the qualification vehicle, the factory-to-pad flow was fully developed for use with each flight vehicle. This system testing was a crucial phase of the program – the proving ground for all hardware from the associate contractors. Details of the "running sell" process were also worked out with the qualification vehicle. This process kept the test flow moving in an orderly way, without action item "stragglers" that became "show-stoppers" at the final sell stage. It also kept the team members aware of each other's status and situation and helped keep the team together.

New Program Requirements

The LMSC adopted new requirements for the development program to avoid on-orbit equipment failures, or at least mitigate their effects. The primary requirement was for redundancy design features, i.e., the "no single failure shall abort the mission" philosophy already discussed. The other requirements included employing computer-driven, system-level testing, establishing the "Monitored Line Parts Program" to assure the program received the best quality parts from the manufacturers, and using a tertiary back-up system (Lifeboat) to provide proper vehicle attitude for RV recovery and SV de-orbit.

Computer-driven testing was required at the system level with RF input and output using vehicle equipment and instrumentation – the system was tested as if in orbit. With limit checking against the vehicle software model, the engineers developed a database that was useful in flight ops support. The team gained experience in understanding data trends, rejecting false anomalies, detecting true anomalies, and developing workarounds to reduce or eliminate mission impact.

As mentioned before, the team's Corona experience with on-orbit equipment failures prompted it to require for Hexagon an improvement in parts quality. Lockheed established the "Monitored Line Parts Program" to assure the best quality parts possible from the manufacturers. The company stationed senior LMSC parts reliability specialists in parts factories monitoring all manufacturing and test operations for compliance to LMSC specifications. To the extent possible, the LMSC provided Monitored Line Parts to other Hexagon contractors as well.

As an additional screening process to get beyond infant mortality on the failure rate curve, the LMSC engineers set a goal that parts were to accumulate 1,000 hours of burn-in testing from parts to module levels.

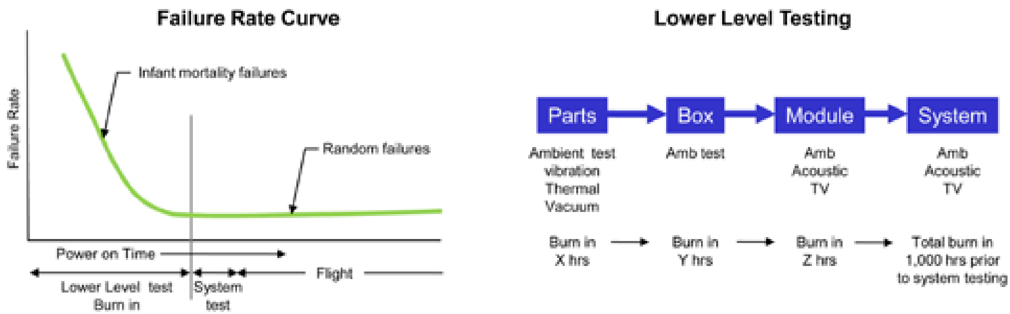


Figure 9. 1,000 Hour Burn-In Screening

For Hexagon's tertiary RV recovery backup system, LMSC adapted the Lifeboat system that had been used on Corona with great success. These backup systems used earth's magnetic field for reference and cold gas thrusters. The program easily incorporated this proven system and provided additional redundancy for critical mission functions.

Hexagon's Flight Success Validated End-to-End Systems Engineering

The NRO operated Hexagon satellites from June 1971—October 1984, 13 years and 4 months, during which time a Hexagon SV was in orbit over 50% of the time. The satellite vehicle and sensor payload proved remarkably reliable, with 19 consecutive intelligence missions successes, a perfect record marred only when the last Hexagon satellite, M1220, failed to get into orbit after a launch vehicle failure destroyed the satellite. Although its development took longer than originally projected, Hexagon's capability proved worth the extra time and effort as it provided an order of magnitude improvement over Corona in intelligence gathering. The system's most significant contribution to national security came in the confidence it provided to U.S. leadership that negotiated the arms control treaties: Hexagon allowed U.S. leaders, in President Reagan's words, to "trust but verify." Hexagon's extensive coverage revealed Soviet weapons development and deployment—e.g., new mobile ICBM deployments—for the Gambit high-resolution satellite to image for scientific and technical analysis. Near the end of the program, mission lengths had increased to 270 days on orbit (one mission was planned for 300 days), many times the original 30-day requirement, despite no major system changes having been made.

The LMSC's systems integrator role allowed it to play a critical part in ensuring end-to-end system responsibility developing the Hexagon SV. In particular, the company's implementation of a top-down systems engineering process, with integrated plans, schedules, requirements, and factory-to-pad testing processes paid dividends in highly reliable and robust Hexagon satellites. Rigorous program management, which likewise emphasized the top-down approach with strong program controls, allowed the program to meet the demanding performance requirements and keep to cost and schedule milestones. There were failures during flight, and unforeseen problems arose, but the experienced flight support team, operating the flexible vehicle that had been built, never failed to accomplish the core intelligence and mapping missions because of an on-orbit anomaly.

System-level test operations that the program had implemented gave the flight support team experience with handling such anomalies, and the built-in design redundancies provided the insurance against catastrophic failure.

Sam Araki was a Chief Systems Engineer on the Hexagon Program. His career in national reconnaissance and the space industry spanned more than 38 years, including recognition by both the National Reconnaissance Office (NRO) and the National Academy of Engineering. He pioneered the development of Agena, the spacecraft used for many NRO imagery and signals intelligence satellites of the 1960s and 70s, including Corona, the world's first photoreconnaissance satellite. In 2004, DNRO Peter Teets recognized his contributions by naming him a Pioneer of National Reconnaissance, and a year later, he received jointly with four others the Charles Stark Draper Prize for Engineering for his work on the Corona program.

Steve Treat worked on the Hexagon Program for Lockheed from the company's drafting of the system proposal in 1966 through the flight of satellite vehicle 1216 in 1980-81. During that time he advanced to Chief Systems Engineer and, eventually, Lockheed Program Manager on Hexagon. Mr. Treat joined Lockheed in 1961 as a space systems engineer with an emphasis in program requirements definition, technical management, and program integration. His assignments included the NASA Ranger program, the Air Force Snapshot Nuclear Reactor Flight Test Program, and early LMSC work on the space segment of the Space Telescope.

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Oder, F. C. E.; Fitzpatrick, J. C.; & Worthman, P. E. (1992). *The HEXAGON Story.* Chantilly, VA: National Reconnaissance Office (NRO).

Appendix A: Hexagon Flight Operations

The chart in this Appendix depicts an assessment of the degree to which all 19 flights and mission elements satisfied mission objectives.

Hexagon program operations supported these mission elements:

- Search and surveillance (S&S) mission with 4 pan camera film recoveries on each flight
- Separate MC&G mission (separate hardware and no interaction with S&S mission) with 1 mapping camera film recovery, on SVs 5 through 16

The mission success is indicated by color codes with a degree-of-success attached to each color as follows:

- blue/green are 1 = complete success in satisfying mission objectives;
- yellow is ½ = partial success;
- red is zero = complete failure.

Assessment is by mission segment where the Search and Surveillance mission has 4 segments per SV, 1 per RV, 76 in all. The MC&G and S-cubed mapping missions have 1 segment per SV.

For the whole 1–19 flight program, degree of success is assessed at 90%. For mission elements, assessment is::

- Search and Surveillance 88% (76 mission segments)
- MC&G Mission 100% (12 mission segments)
- S-cubed mapping element 100% (3 mission segments)

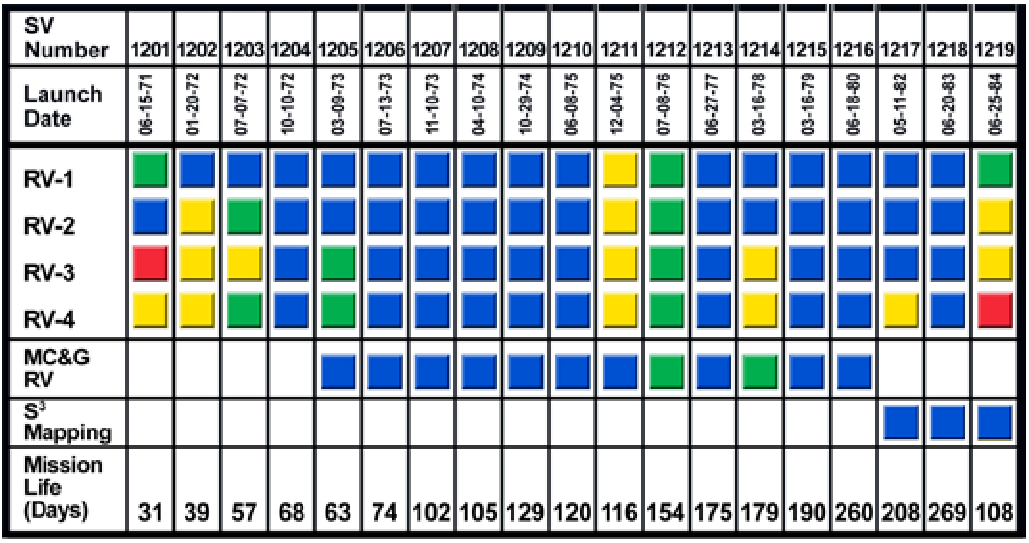
HEXAGON Coverage Achievements—First 12 Pan Missions and MCS Missions

As flight durations grew to several times the initial requirement, the flight system continued its high level of performance. For example, growth in mission life allowed exploitation of growth in film load from 200K feet to 300K feet due to film improvements and a 15% gain in film use efficiency from film path improvements.

Figures for both the pan camera and MC&G missions show coverage achievements well beyond requirements.

Assigning half-value to any mission segment not satisfying all objectives is arbitrary and may be way off the mark.

HEXAGON Flight Operations



PERFORMANCE EVALUATION - Satisfaction of Mission Objectives

For combining mission segments, blue & green = 1, yellow = 1/2, red = zero:

- 90% for the 19 Flight program
- 88% for Search and Surveillance
- 100% for MC&G
- 100% for S^3 mapping

– Air catch and water recovery are both normal operations

– All SVs deorbited as planned.

■ **All mission objectives met or exceeded**

■ **All mission objectives met employing workarounds, redundant/backup equipment.**

■ **Some mission objectives not met.**

SV 1 – RV 1/2 film load limit; parachute problem
SV 2 , SV3, SV11, SV14, SV17– Mono camera operation
SV19 – Limited operations; command system problems

■ **No mission data – complete failure**

SV1 – RV lost on water impact; parachute failure
SV19 – RV not used; flight ended on ECS failure

Appendix B: HEXAGON Coverage Achievements

HEXAGON Pan Camera Coverage Amounts (First 12 Missions)

HEXAGON Coverage Achievements

KH-9 Missions			Coverage Accomplishments (Millions square nm)					
			Worldwide		Communist Countries and Middle East			
						Cloud-Free		
Mission Number	Launch Recovery Dates	Life Time Days*	Total Imagery	Gross Cloud-Free	Total Imagery	Gross	Unique	Unique Targets Imaged**
1201	15 Jun 71–16 Jul 71	31***	15.9	8.3	11.2	3.6	3.2	6,932
1202	20 Jan 72–28 Feb 72	39	21.1	15.4	16.1	12.7	11.0	10,488
1203	7 Jul 72–12 Sep 72	57	26.4	16.4	22.5	13.8	11.5	11,813
1204	10 Oct 72–17 Dec 72	68	18.8	12.0	14.2	9.1	5.6	10,155
1205	9 Mar 73–11 May 73	63	17.5	12.7	12.7	9.4	6.3	11,074
1206	13 Jul 73–25 Sep 73	74	18.9	12.4	15.1	9.6	6.2	12,011
1207	10 Nov 73–20 Feb 74	102	18.0	14.3	13.9	11.4	7.3	12,852
1208	10 Apr 74–24 Jul 74	105	16.6	11.9	13.0	9.3	6.3	12,101
1209	29 Oct 74–7 Mar 75	129	18.6	14.4	14.1	11.2	7.6	13,696
1210	8 Jun 75–6 Oct 75	120	17.4	13.5	13.6	10.7	5.6	13,664
1211	4 Dec 75–29 Mar 76	116	23.1	17.3	17.6	14.1	8.2	14,275
1212	8 Jul 76–9 Dec 76	154	17.9	12.5	12.6	8.9	6.2	14,827
1213	27 Jun 77–19 Dec 77	175	N/A	N/A	N/A	N/A	N/A	N/A
1214	16 Mar 78–9 Sep 78	179	N/A	N/A	N/A	N/A	N/A	N/A
1215	16 Mar 79–19 Sep 79	190	N/A	N/A	N/A	N/A	N/A	N/A
1216	18 Jun 80–15 Mar 81	260	N/A	N/A	N/A	N/A	N/A	N/A
1217	11 May 82–30 Nov 82	208	N/A	N/A	N/A	N/A	N/A	N/A
1218	20 Jun 83–16 Mar 84	269	N/A	N/A	N/A	N/A	N/A	N/A
1219	25 Jun 84–11 Oct 84	108	N/A	N/A	N/A	N/A	N/A	N/A
1220	(Mission lost in launch explosion)	0	N/A	N/A	N/A	N/A	N/A	N/A

* Imaging days on orbit, not counting days of launch as an actual day on orbit.
** COMIREX target population has ranged from about 15,000 in the earlier missions to about 17,000 on the most recent missions.
*** RV-3 was lost on 1201.

HEXAGON Mapping Camera Coverage Amounts

Mapping Camera (12-inch Terrain) Coverage	
Mission	(Thousand of Square Nautical Miles)
1205	5,894
1206	6,282
1207	6,671
1208	6,487
1209	6,773
1210	6,668
1211	6,919
1212	7,363
1213	7,688
1214	13,236
1215	13,782
1216	16,485

The Soviet Target—*Highlights in the Intelligence Value of Gambit and Hexagon, 1963-1984*

Bruce Berkowitz

Like Corona, the Intelligence Community's first successful space-based imagery system, Gambit and Hexagon, its second generation imaging satellites, were products of the Cold War, developed primarily to watch the Soviet Union. Each was designed to fill critical gaps in the Intelligence Community's understanding of the Soviet Union and generally improve the knowledge that was available about the Soviet Union. Gambit provided high-resolution imagery that made possible detailed analysis of specific weapons and facilities. Hexagon provided broad area imagery with sufficient resolution that made it possible to attain at least some information of most targets of interest on a frequent basis.

Each, in its own way, made an important contribution to the U.S. diplomatic, military, and economic strategy of containing the Soviet Union and, in that sense, the eventual success of that strategy. Two decades after the end of the Cold War, it is often difficult to appreciate the challenge that Soviet secrecy presented to the United States. The Soviet regime restricted almost all data, and kept military information especially tight. Indeed, this all-pervading secrecy was perhaps the most significant factor framing U.S. intelligence assessments of the Soviet threat. As one National Intelligence Estimate published in 1960 said, the Soviets "continue to maintain a policy of extreme secrecy, which they evidently view as a major military asset in itself" (Board, 1960a, pp. 2-3). Gambit and Hexagon were an important additional step in penetrating this secrecy.

The Role of Imagery in Penetrating Soviet Secrecy

Corona, which the Intelligence Community operated from August 1960 to May 1972, had been designed primarily as a "search system" to detect, locate, and identify intelligence targets. Corona's first, and probably most notable, success was to effectively settle the "missile gap" controversy that had preoccupied U.S. intelligence since the Soviets tested the first intercontinental ballistic missile (ICBM) in 1957 by providing a high-confidence count of SS-6 launch pads. Corona was a breakthrough, and its performance steadily improved during its operational life so that, where the initial KH-1 Corona camera provided just 40-foot resolution imagery, the final KH-4B camera introduced in 1967 provided imagery of up to 6-foot resolution (McDonald, 1997, pp. 213, 306).

Gambit and Hexagon—Two Missions

Even so, analysts required a "surveillance system" with even greater resolution for technical intelligence on the design and performance of specific weapon systems. Such technical intelligence could include, for example, measuring the exact dimensions of airframes, silos, and gun barrels to assess the capabilities; using assembly joints and fixtures to infer the internal structure of a missile or aircraft; or deducing the function of a weapon by identifying small components such as antennas, external cables, and sensors. Gambit was designed to provide this capability. The Gambit-1 system, which operated from July 1963 to June 1967, provided resolution of 2-3 foot ground resolved distance (GRD) under typical conditions using the KH-7 camera system.[1] Its successor, Gambit-3,[2] which used the KH-8 camera system and operated between July 1966 and April 1984, initially provided imagery in the two-foot resolution range and, in its later missions, routinely provided better than two-foot resolution imagery (Oder, Fitzpatrick, and Worthman, 1991).

So, where Corona's KH-4 camera might permit an analyst to identify a moored ship as a submarine, Gambit-1's KH-7 camera could enable him or her to positively identify the submarine as a Hotel-class SSBN, and Gambit-3's KH-8 camera could see the separation lines indicating hatches in the sail housing three ballistic missiles. Gambit-3 imagery could also provide wing numbers of aircraft, identify specific vehicles parked in a motorized regiment (see Figure 1), or reveal the design details of a new aircraft carrier under construction (see Figure 2).

Figure 1. KH-8 (M4331) image of motorized rifle regiment, Gusinoozersk, former Soviet Union, 27 April 1971.

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1 Spatial resolution refers to the detail discernable in an image, or, in the case of imint satellites, the smallest size object a satellite can detect. Resolution depends on many factors, including the amount of light a satellite sensor takes in, the optical characteristics of the sensor, the fineness of the film or array used to detect the light, the pointing precision and stability of the satellite, and the distance of the satellite from the object it is imaging (Oder, Fitzpatrick, and Worthman, 1991, p. 101).

2 There was no Gambit-2. The numbering of the two Gambit systems was a result of the numbering of design alternatives that were selected during the development process.

Figure 2. KH-8 (M4354) image of aircraft carrier under construction, Mykolayiv, former Soviet Union, 4 July 1984.

In addition to higher resolution imagery for technical analyses, analysts also required greater total quantities of imagery, and synoptic coverage to provide reliable counts of individual ships, tanks, aircraft, truck-mounted missile launchers, and other mobile targets. This was the task for which Hexagon was developed.

Hexagon, first launched in June 1971 and continuing in operation through October 1984, provided significantly greater coverage than Corona, and resolution as good as that provided by Gambit-1. Hexagon was designed to image 80-90 percent of the built-up areas of the Soviet Union twice a year. Just as important, a single Hexagon swath—about twice that of Corona—could cover an area 300 by 7,000 nautical miles (nm), so analysts could scan a very large area for a suspected target, and then “zoom in” by magnifying the image to identify it (Oder, Fitzpatrick, and Worthman, 1992, pp. 119, 133).

Although Gambit and Hexagon were designed to address two different sets of requirements, in practice the imagery from the systems was co-mingled in common databases, and analysts used whatever imagery was available for a target and was of sufficient quality to meet the need at hand. An analyst might use Hexagon imagery to assess the design and capability of a Soviet weapon system if that was all that was available. Similarly, one might use Gambit imagery to detect and locate a target if it happened to capture it within its limited field of view.

Effectiveness and Limitations

The U.S. overhead imagery program was in full swing by 1965 with the continuing Corona program and the maturing Gambit-1. The combination of search and surveillance satellites provided a steady stream of imagery that transformed U.S. intelligence—in 1965, a total of 355,553 feet of KH-4 film and 9,725 feet of KH-7 film (NPIC, 1968, p. 11). One program summary filed that year reported that, "The satellite photo reconnaissance program contributed more than any other source to military intelligence on the Sino-Soviet Bloc," and "furnishes the most reliable information on the status of Soviet R&D efforts and on the capabilities and posture of Soviet military forces." It went on to add that "the results of this photographic collection effort collated with other intelligence information has had a major impact on NATO and national targeting and military force application planning" (Classified source, CSNR reference collection).

Even so, like Corona, Gambit and Hexagon had inherent limitations. The NRO did not have a satellite in orbit continuously, and even when a satellite was available, it was often several days before orbital mechanics put it in the position needed to image a particular location. Because film-return satellites had to fly low to perform effectively (100 nm over the Soviet Union for Corona, 80 nm for Gambit, 90 for Hexagon), operators had to regularly make orbital adjustments to keep the satellite from reentering, and these adjustments often came at the expense of imaging opportunities. In addition, weather—specifically, cloud cover—was always an obstacle that had to be navigated.[3]

As a result, weeks or even months could pass before an opportunity occurred to image a particular target. In addition, there were inevitably delays between when an image was captured and when it landed on an imagery analyst's light table. Even after collecting an image, one could not deorbit a film capsule without sacrificing the unused film. Once a capsule was deorbited, it was necessary to recover it in a mid-air catch over the Pacific Ocean, ship the film to Rochester, New York for processing, and then send the finished product to Washington, D.C. for exploitation. Even under ideal conditions the film that an imagery analyst used was typically several days to months old.

This extended cycle time, inherent to film-return satellites, inevitably affected the focus and operational tempo of analysis. Also, because the imaging capabilities of Gambit and Hexagon were considered so sensitive, and because it was challenging to disseminate a product that was usually in hardcopy and text, the number of consumers was much smaller than what we see today, where satellite imagery is so much more widely available, both within the Intelligence Community and society as a whole.

3 On a typical mission, 70–75 percent of the collected imagery might be "cloud free." See Oder, Fitzpatrick, and Worthman, 1992.

Gambit and Hexagon Imagery and Assessments of the Soviet Target

One way to illustrate the impact of the second-generation U.S. imaging satellites is to consider how they contributed to satisfying three of the major intelligence challenges of the Cold War era:

- Estimating Soviet strategic nuclear forces—that is, identifying Soviet strategic weapons under development and forecasting the numbers that the Soviets would deploy;
- Monitoring Soviet compliance with strategic arms control agreements to ensure that the Soviets had not exceeded treaty ceilings, that they had destroyed weapons as required, and had not deployed weapons that the treaty had banned; and
- Supporting deterrence policy by providing order of battle, target databases, maps and charts, and other information used in the development of military operational plans for a conflict in Europe or strategic nuclear strike against the Soviet bloc.

Estimating Soviet Strategic Forces

The Soviet Union developed strategic weapons in four distinct generations during the Cold War.[4] The first appeared in the mid- to late-1950s, consisting of the long-range Tu-95 "Bear" and Mya-4 "Bison" intercontinental bombers; the SS-6 ICBM; and the diesel-electric powered "Zulu" and "Golf" class ballistic missile submarines. A second generation appeared in the early 1960s, consisting of the SS-7 and SS-8 ICBMs, and the "Hotel" class nuclear powered ballistic missile submarines. A third generation appeared in the late 1960s and into the early 1970s, consisting of the "light" SS-11 and SS-13 ICBMs, "heavy" SS-9 ICBMs, and the "Yankee" class ballistic missile submarine. And a fourth generation emerged in the early 1970s through the 1990s, consisting of the SS-17 and SS-19 ICBMs (significantly larger replacements for the SS-11); the SS-18 ICBM (an SS-9 replacement); the SS-16 mobile ICBM; and the "Delta" and "Typhoon" class ballistic missile submarines.

United States analysts at the time faced a challenge akin to piecing together a puzzle—except that, in this case, instead of coming in a box with a picture showing how the assembled puzzle should appear, analysts got the pieces just a few at a time, had no idea what the final picture should look like, and, to make the problem even harder, often included extra pieces (in the form of programs, like the tested-but-cancelled SS-10 ICBM), and pieces that might plausibly fit together several different ways (like the Tu-22M "Backfire" bomber, probably a theater weapon, but which also had the range to reach the United States).

Satellite imagery did not completely solve the challenge, but provided an enormous assist. Corona transformed the process of counting operational Soviet missiles from one

4 For a comprehensive history of the development of Soviet strategic nuclear forces, see Podvig (2001). According to Podvig, the Soviets themselves did not consider their earliest ICBMs or ballistic missile submarines to be viable weapons, and would describe the evolution of their nuclear forces during this period as occurring in three phases, beginning with the SS-7.

based mainly on deductive reasoning (e.g., extrapolations of how many missiles the Soviets could have built with a given amount of factory floor space) into one based on hard data. By 1961 U.S. analysts knew the true size of the Soviet ICBM force because Corona imagery offered, in the words of the annual assessment of Soviet strategic capabilities, "New information, providing a much firmer base for estimates," resulting in "a sharp downward revision in our estimate of present Soviet ICBM strength" (Board, 1961b).

Gambit-1 imagery took this achievement a step further, and began to influence U.S. estimates soon after it became available in July 1963. For example, Gambit made it possible not only to see that the Soviets were building new missile launchers, but also to analyze with greater precision what kinds of missiles the Soviets were about to deploy. Similarly, when the Soviets began to build a new class of ballistic missile submarines, Gambit imagery made it possible to identify the components as they were being assembled. This was apparent in the 1964 National Intelligence Estimate of Soviet strategic forces, which noted that

> Major changes in Soviet programs for the development of strategic attack forces have become apparent during the past year. In 1962–63, certain ICBM and ballistic missile submarine programs came to an end *[a reference to the SS-7, SS-8, and Hotel-class ballistic missile submarines],* and a pause ensued in the growth of these forces. At the same time, the pace of ICBM research and development increased markedly *[a reference to observed activities at Plesetsk and Tyuratam missile test centers].* More recently, the USSR has resumed ICBM deployment in a new improved configuration *[a reference to silos replacing above-ground launch pads],* and the probable advent of a new submarine which we believe is designed to carry ballistic missiles probably marks the start of another deployment program *[a reference to early Yankee-class submarine activity observed in Severodvinsk].* (Board of National Estimates, 1964a, p. 1)

This pattern was repeated throughout the 1960s and 1970s; the first definitive indicator that a weapon was being deployed would be the detection in satellite imagery of a previously unobserved test system, component, or support apparatus. As the capabilities of U.S. imaging systems became more widely known, the Soviets gradually tried harder to conceal their military development efforts [See accompanying box: "How Much Did They Know?"]. Thus, one important contribution of Hexagon was just in the sheer volume of data that the system provided analysts. Hexagon's capacity made it possible to collect imagery more frequently and over larger areas. Analysts could be reasonably sure that they had at least some imagery of a Soviet site, or could eventually obtain it. Hexagon gave analysts a greater level of confidence that they had not missed potential targets of interest. Even more significantly, thanks largely to Hexagon, imagery became a routine part of analysis that analysts and intelligence consumers came to expect.

Gambit and Hexagon imagery also made it possible for U.S. analysts to understand Soviet strategic weapons at a new level of detail, making it possible, for example, to analyze the mechanical systems of Soviet submarines as they were being installed or maintained, and other technical features (see Figure 3). This, in turn, made it possible for the U.S. to develop more effective anti-submarine weapons and countermeasures. By monitoring missile silos under construction (see Figure 4), Gambit and, to a lesser degree, Hexagon imagery made it possible to analyze their hardness and reload capability which, in turn, offered insights into Soviet preparations for nuclear war and how they envisioned one might unfold (Classified source, CSNR reference collection) . This was also important for military operational planning, as we shall see shortly.

Figure 3. KH-8 (M4323) image of Soviet submarine,
Komsomolsk Shipyard, former Soviet Union, 16 September 1969.

A typical Gambit mission yielded over 13,000 unique target images. A typical Hexagon mission would image roughly 15 to 25 million square miles of territory, encompassing from 10,000 to 14,000 unique targets. A single mission would generate several Photographic Interpretation Reports, typically consisting of 40–50 pages summarizing observations of the targets imaged by the mission. This volume of data and reporting suggests the institutional knowledge that U.S. analysts developed as they became intimately familiar with specific targets that were beyond the reach of any other means of observation.[5]

5 NPIC reports were organized by target category and geographically. Target categories included: Offensive Missiles, Defensive Missiles, Other Missiles, Aviation, Naval, Ground Forces, Electronics, Nuclear, Biological/Chemical Weapons, Urban/Industrial Sites, MC&G, and Other. Geographical areas included the USSR and China, Eastern Europe, Western Europe, Middle East, North Africa, Central and South Africa, South America, Central America, South Asia, Southeast Asia and Pacific, and others (Classified source, CSNR reference collection).

Figure 4. KH-8 (M4315) image of ICBM complex, Yoshkarola, former Soviet Union, 12 August 1968.

Monitoring Arms Control

Arms control was a centerpiece of U.S.-Soviet relations during the Cold War, and especially after 1969, when the Nixon administration entered office, determined to negotiate a ceiling on the two nations' strategic weapons. Arms control required U.S. intelligence to monitor Soviet compliance, and Gambit and Hexagon were essential to the effort.

The United States and the Soviet Union signed two treaties on 26 May 1972. One limited offensive nuclear weapons: the *Interim Agreement Between the United States and the Union of Soviet Socialists Republics on Certain Measures with Respect to the Limitation of Strategic Offensive Arms,* more often referred to as the Strategic Arms Limitation Treaty or, simply, "SALT." The treaty capped each nation's ICBMs, SLBMs, and manned bombers, and banned the construction of new ICBM launchers. It allowed the two countries to replace some older weapons with new ones, but prohibited either from increasing the internal volume of an ICBM silo by more than 10–15 percent.

As a result, SALT required U.S. intelligence to determine whether the Soviets had dismantled or destroyed prohibited weapons according to procedures established under the Standing Consultative Committee the treaty established. These included blowing up older SS-7 and SS-8 ICBM launchers, or cutting up Mya-4 bombers, and then leaving the remains so that U.S. satellites could image them. United States analysts used both

Gambit and Hexagon imagery for this. United States intelligence also had to determine whether the Soviet Union had enlarged its existing silos more than the permitted 10–15 percent.[6] Such a violation could be a matter of just a few cubic meters, and a complete analysis essentially required estimating the entire depth, diameter, and internal features of a silo. One approach was to use satellite imagery to measure silo components prior to assembly, such as the concrete liners staged next to the construction site. The second treaty *Soviet and U.S. leaders signed was the Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems,* better known as the "ABM Treaty." This agreement limited each side to two ABM sites, later modified to limit both sides to a single site. Experts had disagreed as to whether the Soviet Union had been building such a system, and one of the accomplishments of Gambit-1 was to image the Soviet S-200 (called the SA-5 or "Gammon" in the West) anti-aircraft missile, which eventually analysts proceeded to assess was not an ABM, and later, the A-350 missile system (Western designation ABM-1 or "Galosh"), which analysts concluded was, in fact, an ABM. Hexagon imagery was useful in providing the broad area coverage needed to search for and rule out sites that would have been a violation of the ABM cap.

Counting missile launchers and submarines, both operational and destroyed under the terms of the treaty, was straightforward, given the procedures the Soviets and the Americans adopted at the Standing Consultative Committee (SCC) to facilitate monitoring. But it was much harder to detect potential Soviet violations outside the SCC procedures—weapons that the Soviets were prohibited from having, and allegedly trying to hide—or actually hiding, and denying. Gambit and Hexagon were critical to this task as well.

The Soviet Union began, in the mid 1970s, to deploy several weapon systems that challenged U.S. treaty monitoring capabilities. One was the new SS-16, the first successful mobile ICBM. The SS-16, which the Soviets began to develop in 1969 and tested in 1972, presented two problems. Aside from the fact that mobile missiles are inherently harder to count and easier to hide, the SS-16 was closely related to the SS-20 intermediate range ballistic missile, which was essentially an SS-16 minus the first stage. The 1971 SALT agreement banned mobile ICBMs, including the SS-16, but was silent on the SS-20, which the Soviets proceeded to deploy. Gambit imagery of SS-20 facilities showed that the missile's transporter-erector-launcher (TEL), as well as the shelters in which it was stored, provided ample room for an SS-16. The issue remained controversial in the United States until December 1987 when the United States and Soviet Union signed the Intermediate Nuclear Force (INF) Treaty, which required the Soviets to retire and destroy its SS-20s.

As noted, Hexagon's more significant contribution to arms control monitoring was probably its capability to assure U.S. officials that there were few "blind spots" in which they were likely to miss a Soviet violation. It was Hexagon, for example, that eventually located the Soviet ballistic missile defense radar under construction at Krasnoyarsk in violation of the ABM Treaty. The treaty required each country to position missile defense

6 The treaty prohibited replacing an existing silo with one that had "significantly increased" dimensions. The United States tabled a statement on the day the treaty was signed that "significantly increased" meant that "an increase will not be greater than 10-15 percent of the present dimensions," and the Soviet Union accepted that definition.

radars at the periphery of their territory, facing outward; this was intended to limit them to a warning role, rather than a battle management role. In the early 1980s, the Soviets filled a gap in their coverage by building a radar located (probably for cost reasons) well in the interior of their territory. The Soviets did not reveal the project, but after considerable effort, the violation was confirmed in Hexagon imagery. The Soviets agreed in 1989 to dismantle the facility.

Support to Military Planning

Though neither Gambit nor Hexagon was suited to providing current information to military commanders in the field, the two systems were extremely important in providing military commanders and planners data critical for force planning and developing operational plans. These included a reliable order of battle of targeting data for U.S. strategic nuclear forces and military-grade maps.

Soon after Gambit-3 entered operation, the Defense Intelligence Agency (DIA) reported that, for the first time, it was possible to identify and count specific models of tanks and artillery pieces as the Soviets introduced them into service. For example, Gambit-3 could distinguish a new T-62 tank from its older, but visually similar, T-54 and T-55 counterparts. By making it possible to count individual trucks and armored vehicles deployed at their barracks, Gambit and Hexagon provided better estimates of the actual strength and readiness of units. Gambit imagery was also valuable for developing target lists of Soviet military facilities, defense plants, and infrastructure for the Single Integrated Operational Plan, or "SIOP," that U.S. strategic nuclear forces depended on. The SIOP planners at the Joint Strategic Target Planning Staff, working with target analysts at DIA, used overhead imagery to assess the function and hardness of specific candidate targets to meet targeting guidelines, which were themselves tied to U.S. policy. Gambit imagery made it possible to develop detailed assessments of the layout of a defense plant, its construction details, its flow of operations, and its susceptibility to damage, and so planners could assign each warhead in the U.S. force to a specific aim point for maximum efficiency (see Figure 5).

For its part, Hexagon revolutionized the field of mapping, charting, and geodesy (MC&G), vital for planning military operations. No other system had been able to provide the required volume of coverage at the level of accuracy required for military-grade maps. This is easy to under-appreciate today, when maps are ubiquitous and, with the help of GPS, it is possible to locate one's position almost anywhere with a precision of a few feet. In the 1960s and even the 1970s, however, maps were much harder to produce simply because the information required to make them had to collected by on-the-ground surveys or, at best, imagery taken over many years from aircraft.

In addition to imagery from Hexagon's main cameras, Missions 1205 through 1216 provided imagery specifically collected for MC&G with a separate 12-inch focal length Mapping Camera Subsystem (MCS) mounted on the forward end of the spacecraft. The MCS was supported by a Doppler beacon and accelerometer to facilitate geolocation, and a separate film supply and recovery bucket.[7] The original MC&G requirement for Hexagon was to provide 7-10 million square miles of the “free world” each year, which was met partly by the KH-9 pan and partly by the KH-9 MCS (Oder et al., 1992). In the 1970s through the following decades U.S. Government agencies responsible for producing maps were almost entirely dependent on Hexagon data. Hexagon imagery remains important for MC&G even today, as there has never been a direct replacement for its combination of coverage and precision.[8]

Figure 5. KH-8 (M4301) image of ammunition loading and explosives plant, Kemerovo, former Soviet Union, 3 August 1966.

7 MC&G imagery requires, in addition to the image itself, mapping support data (MSD) that provides precise information on the imaging satellite’s positions, velocity, acceleration, and attitude, in addition to time data. These data make it possible to assign precise longitude, latitude, and elevation to objects or features on the image, and, from there, to maps and other products.

8 The Shuttle Radar Topography Mission, a joint mission carried out in February 2000 by the National Aeronautics and Space Administration, the National Imagery and Mapping Agency (now NGA), and the German Space Agency, employed a radar mounted on the Space Shuttle Endeavour to produce an elevation dataset for most of the earth’s surface, and numerous commercial satellites have collected electro-optical imagery used in mapping. Even so, the mapping data generated by Hexagon remains unique.

Conclusions

Gambit and Hexagon penetrated Soviet secrecy, providing a level of understanding of the Soviet target that would have otherwise been impossible. Each of the systems complemented the other.

The 1991 NRO history of the Gambit program, citing U.S. defense planners, argued that one of the greatest contributions of Gambit was the money it helped to save that would have otherwise been required to develop U.S. weapon systems to the "worst case" potential threat. It went on to quote from a 1981 National Photographic Interpretation Center (NPIC) study that had identified a list of specific issues concerning Soviet developments on which Gambit provided significant intelligence information. These included:[9]

- Soviet strategic submarine developments, with emphasis on the Yankee and Delta class boats;
- The Soviet lunar program, especially the construction of the launch site of the would-be Soviet moon rocket, at Tyuratam; (see Figure 6)
- A reliable order of battle for Soviet ground forces;
- The Soviet strategic missile program, especially the SS-9;
- Variations in specific Soviet aircraft, such as the different models of Tu-95 "Bear" bombers;
- Communications vehicles and equipment;
- Soviet strategic defenses—in particular, resolving the controversy over the true mission of the SA-5;
- The development of solid rocket motors at Palograd;
- The SS-16/SS-20 development, from initiation to deployment;
- The "Caspian Sea Monster," a large surface effects test vehicle;
- Soviet space surveillance systems;
- Various Soviet efforts at camouflage, concealment, and deception; and
- The monitoring of arms transfers.

9 In addition, the NPIC study also cited several significant, specific intelligence contributions against non-Soviet targets, including suspected "advanced weapon-related facilities" in China, and Chinese electronic systems. The study also said that Gambit made significant contributions in dealing with various world-wide crises, notwithstanding the limitations of film-return systems.

Figure 6. KH-8 (M4316) image of Tyuratam Missile Test Center, Kazakstan, former Soviet Union, 19 September 1968.

Not surprisingly, the 1992 NRO history of the Hexagon program, written as part of the same series, focused on the enormous capacity of Hexagon in citing examples of the system's value. Noting that on a typical mission Hexagon would image about 80 percent of the Soviet Union's 7 million square nautical miles, cloud-free, Hexagon could, for example:

- Image all of the SS-7 sites scheduled for dismantling under SALT;
- Monitor changes in the status of Soviet ground forces by imaging, if necessary, an entire military district on a single mission;
- Provide a continuing order of battle for Soviet naval and air forces by repeated imaging of their bases;
- Monitor large-scale Soviet military exercises;
- Provide continuing coverage of nuclear test facilities; and
- Provide economic intelligence, in the form of monitoring Soviet crop yields and natural disasters that might disrupt Soviet manufacturing capabilities.

Yet, ironically, in contrast to Corona, which settled the "missile gap" controversy, Gambit and Hexagon may have created at least as many disagreements among analysts as they created points of consensus. For example, questions such as whether the Soviets could reload their ICBM silos after an initial salvo in a nuclear war, or whether the Soviets had a significant civil defense program, or whether the Soviets were systematically violating the SALT agreements and ABM Treaty were all controversial during the Cold War. There was more hard data available, but it was still incomplete. Thus it was possible for analysts to reach different conclusions using Gambit and Hexagon imagery. The difference was that now such disagreements reflected the assessments of better-informed analysts.

The most important contribution of the two systems is that they were both important steps in making satellite imagery a routine part of intelligence analysis—Gambit, by introducing technical analysis from space, and Hexagon by changing the assumption that satellite imagery was an inherently scarce data source. By truly integrating satellite imagery into the intelligence process, the two systems were key steps in establishing overhead reconnaissance as we know it today.

WHAT DID THE SOVIETS KNOW?

The value of Gambit and Hexagon depended directly on whether the Soviets understood the capabilities of the two systems well enough to evade them or take countermeasures. Indeed, Soviet concealment, denial, and deception (CD&D) was a contentious issue within the Intelligence Community throughout the lifetimes of Gambit and Hexagon, and it was unclear at the time exactly how much the Soviets knew.

Arms control was an important factor in "disclosing" the capabilities of the two systems. To facilitate Senate ratification of SALT and the ABM Treaty in 1971-72, the Nixon administration considered officially acknowledging U.S. imaging systems, but decided instead to suffice with the reference to "national technical means" (NTM) for verification. Naturally, the treaty limits, and the agreement by the Soviets not to impede NTM, implied at least some of the capabilities of Gambit and Hexagon.

General references to U.S. imagery satellites appeared in the media even in the 1960s, but the first account that offered generally accurate descriptions of Gambit and Hexagon appears to have been a 1978 issue of *Spaceflight* though the magazine did not use their names. The 6 October 1980 edition of *Aviation Week and Space Technology* also referenced the two systems. After that, numerous books, articles, and websites cited these articles and provided additional information (sometimes accurate, often erroneous) either obtained from unidentified sources or deduced from the outside configuration of the systems.

Several incidents resulted in public disclosure of Gambit or Hexagon imagery, which could have been analyzed to assess the capabilities of the systems. In one case, following the 1979 seizure of the U.S. Embassy in Tehran, an Iranian magazine published what it said were U.S. satellite images that the "students" occupying the complex had found. During the following decade there were several inadvertent disclosures of imagery and descriptions of the capabilities of the two systems by U.S. officials.

Examples of Gambit and Hexagon imagery were also likely compromised as a result of espionage. John Anthony Walker, Jr., who spied for the Soviet Union from 1967 through 1985, and Jerry Alfred Whitworth, whom Walker recruited in 1974, provided their Soviet handlers cryptographic materials, and this would have made it possible for them to have intercepted Gambit and Hexagon imagery transmitted on communications systems thought to be secure.

Robert Philip Hanssen, an FBI special agent who intermittently spied for the Soviet Union and Russia, was briefed into imagery intelligence compartments in 1981 and served as the FBI's liaison officer to the NRO in 1983. However, Hanssen broke contact with his handlers in 1981, and only resumed spying in 1985. In 1985 Aldrich Hazen Ames did give intelligence products containing Gambit and Hexagon imagery to the Soviets.

GAMBIT, HEXAGON AND NON-SOVIET TARGETS

The Soviet Union was, of course, not the only Cold War-era intelligence target. United States officials also were concerned with other threats, such as nuclear proliferation, regional conflicts, and China. Gambit and Hexagon played a role in covering all of them, with Hexagon proving especially important. Well into the late 1960s, U.S. intelligence had little or no imagery for most regions outside the Soviet Union, Eastern Europe, and China, simply because of a lack of capacity and the lower priority assigned targets in the rest of the world.

Hexagon changed this. The vast capacity of the system made it possible to obtain at least some imagery for most of the earth's surface. Hexagon's broad area coverage made the system especially important in situations such as confirming reports of nuclear weapons program in various countries. Hexagon was capable of imaging the entire territory of these countries, making it possible to ascertain the status of their nuclear programs with a high level of confidence.

Even so, during the film-return era there also were cases in which the limitations of film-return systems made it impossible to cover certain major world events, even in critical situations. For example, the 1973 Arab-Israeli War highlighted the urgent requirement for near-real-time imaging capability. Secretary of State Henry Kissinger, in consultation with President Richard Nixon, ordered the premature return of one of the film capsules in order to obtain battlefield imagery that was required to support diplomatic efforts. It is always a difficult decision to recover a mission before all the film is exposed and lose opportunities to collect imagery. This requirement for near real-time imaging capability contributed to the transition from film-return systems to electro-optical systems (Fitzgerald, 2005, p. 12).

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