

CORONA: THE FIRST RECONNAISSANCE SATELLITES

The first artificial satellite of Earth was placed in orbit almost 40 years ago. That event, in October 1957, had great political and technological significance. Almost overnight, thoughtful people began to discuss the possible uses of Earth satellites. Two great applications of space technology have emerged since then. Communication satellites in synchronous orbit now play a prominent role in our lives. They complement terrestrial links and offer communication services not previously available. Equally profound has been the development of a worldwide navigation service based on the constellation of Global Positioning System satellites.

Important as these applications are, they were preceded and overshadowed by American reconnaissance satellites, which started to fly in early 1959. These Corona satellites remained one of the nation's most closely guarded secrets for four decades. It was not until 1995 that President Bill Clinton authorized declassification of the Corona satellites' photographic results and technical design.¹ The Corona program was strongly influenced by a number of eminent scientists.

The satellites were built around a panoramic camera that operated near diffraction limits. A fine-grain, high-resolution film was moved through the camera during orbital operations and was then returned to Earth in reentry capsules. The capsules were caught by aircraft as they descended on parachutes. During this pioneering system's 12 years of operation, 145 satellites were placed in low polar orbits by rockets launched from California. One hundred and sixty-seven film capsules were successfully recovered near Hawaii, providing over two million feet of film.

This photographic coverage was a powerful stabilizing influence during the cold war. It eventually made possible the sweeping arms reduction treaties that have now been negotiated. Coming as it did at the beginning of the American space program, it was a remarkable scientific and engineering achievement.

Background

The Central Intelligence Agency developed and operated the Corona program, leading a team of US Air Force units and industrial contractors in a daring technical enterprise. To understand why the nation's first space program was conducted in this unusual way, it is necessary to recall how it began. Corona was an urgent response to presidential concern about the possibility of surprise attack as

Based on remarkable scientific and technical achievements, a series of 145 American spy satellites provided strategic information that helped stabilize East-West relations during the cold war.

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nuclear arsenals began to expand. The concept of surprise attack had become a vivid reality on 7 December 1941, and neither President Harry Truman nor President Dwight Eisenhower could forget that disaster.

Truman believed that adequate intelligence data had been available to warn of pending attack in 1941,

but that those data had been segmented and scattered. As President, he took the initiative to establish a peacetime intelligence service. The purpose of the Central Intelligence Group, which he established in 1945, was to bring all information affecting national security into sharp focus and ensure that policy positions of the various government departments did not color the judgments. That group evolved into the Central Intelligence Agency.

After becoming President in 1953, Eisenhower became increasingly concerned about the possibility of a surprise nuclear attack as the USSR moved quickly to establish a nuclear arsenal.² The possibility of a swift strike became real when Soviet long-range bombers became operational. In March 1954, Eisenhower asked MIT president James Killian to address this problem with his scientific colleagues, and the White House Technological Capabilities Panel was formed. One of its working subgroups focused on the problem of strategic intelligence, and Edwin Land of the Polaroid Corp led that work. This unique and gifted man would go on to guide our reconnaissance activities for the next three decades. His group included Edward Purcell and James Baker of Harvard University, John Tukey of Bell Laboratories, Joseph Kennedy of Polaroid and Allen Donovan of the Cornell Aeronautical Laboratory.

The Killian panel focused much of its attention on the need for good strategic intelligence. The panel members believed that such intelligence had by far the greatest influence on national security. Land described their commitment to me one day: "We simply cannot afford to defend against all possible threats. We must know accurately where the threat is coming from and concentrate our resources in that direction. Only by doing so can we survive the cold war."

The Killian panel enjoyed Eisenhower's complete confidence, and he ensured that it was given access to all facets of American intelligence. The panelists were not impressed by what they found. Their final report would say, "We must find ways to increase the number of hard facts upon which our intelligence estimates are based, to provide better strategic warning, to minimize surprise in the kind of attack, and to reduce the danger of gross overestimation or gross underestimation of the threat. To this end, we recommend adoption of a vigorous program for the extensive use of the most advanced knowledge in science and technology." Killian and Land briefed the President personally on the specific technologies they had in mind. The U-2 spy plane was the first result of their

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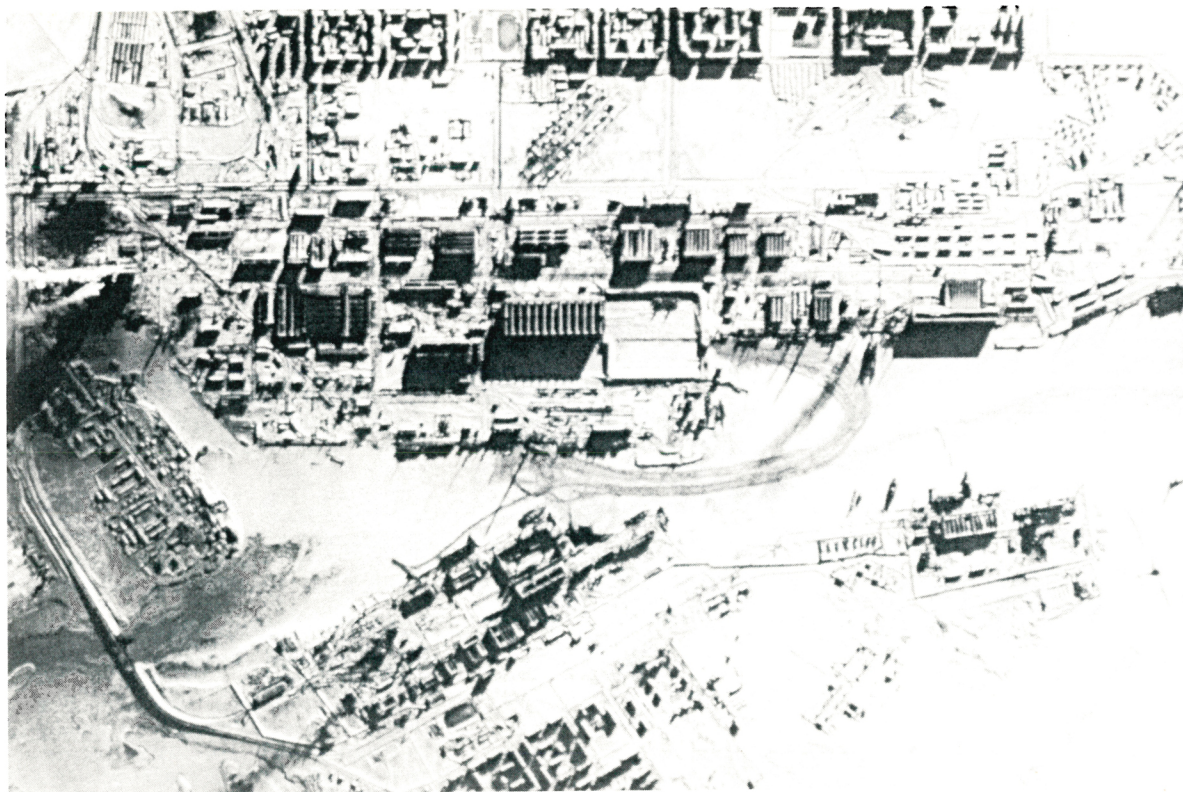


FIGURE 1. CORONA SATELLITE PHOTOGRAPH of the Severodvinsk shipyard near the Arctic Circle, 10 February 1969. This facility was the primary source of diesel and nuclear submarines for the Soviet navy.

strong influence on American presidents and American intelligence.

The accelerated development of intercontinental ballistic missiles gave special urgency to Eisenhower's concern about surprise attack. With only a 30-minute flight time and no realistic prospect for defense, the emerging reality of a Soviet ICBM force put surprise attack at the top of his concerns. The launching of Sputnik in October 1957 crystallized both public and presidential concern. It also compelled senior government people to think seriously about satellite reconnaissance. Eisenhower turned again to Killian, Land and their colleagues for advice.

The US needed a great deal of information about almost every part of the USSR. The USSR had a vigorous missile program, and ICBM launch sites were reported in many places. The Soviet air defense system was vast and the Soviets were developing an antiballistic missile system to counter US long-range missiles. The Soviet nuclear program was vigorous, and the USSR had exploded a usable hydrogen bomb before the US had. An extensive Soviet chemical and biological weapons program was operating. American intelligence could not monitor this vast enterprise with agents on the ground. Although it had been important during the Second World War, communications intelligence was not able to follow these activities.

The initial expectation had been that the CIA's U-2 program could operate for only a year or two. By 1957, it was in its second year of overflights. These missions were necessarily few in number and could not survey large areas. It was unrealistic to rely on them for guiding national policy in the nuclear missile era. Satellites offered a unique solution.

Need for satellites

In 1945 the Air Force had commissioned the Rand Corp to examine the possibility of launching satellites for mili-

tary purposes. Early Rand studies defined the feasibility of reconnaissance from space and identified the appropriate low-altitude orbits passing roughly over the North and South Poles. Long-range missiles then being designed offered the means for lifting reconnaissance satellites into such orbits. Rand technical people, working with a growing cadre of Air Force officers, became untiring advocates for satellite reconnaissance. Their proposals were met by considerable skepticism, because space flight had not yet entered the consciousness of the public and government officials, as it soon would with a vengeance.

Rand's work focused primarily on the requirements of the Strategic Air Command, which was then the dominant voice in the Air Force. SAC thought it needed poststrike bomb damage assessment. That would allow targets that were missed by the first wave of bombers to be retargeted for subsequent attack. The photographic resolution required for this task was not great, because one would be trying to locate large craters in relation to cities and military bases. On the other hand, this information would be needed promptly. These requirements were addressed in the satellite system proposed by Rand in 1954.³ Rand's solution was based on a real-time television-readout satellite operating 300 miles above Earth's surface. It would have a resolution of 100 feet or more. Rand's studies became the blueprint for the photographic reconnaissance component of the Air Force WS-117L program, called Samos.

Eisenhower asked his Foreign Intelligence Advisory Board to review the Samos program and recommend what ought to be done. The board's report of late 1957 was skeptical that Samos would provide good strategic intelligence. Its resolution was limited by a small focal length and the bandwidth of the downlink. The program was running late and encountering serious technical problems; RCA was responsible for developing the television sensor

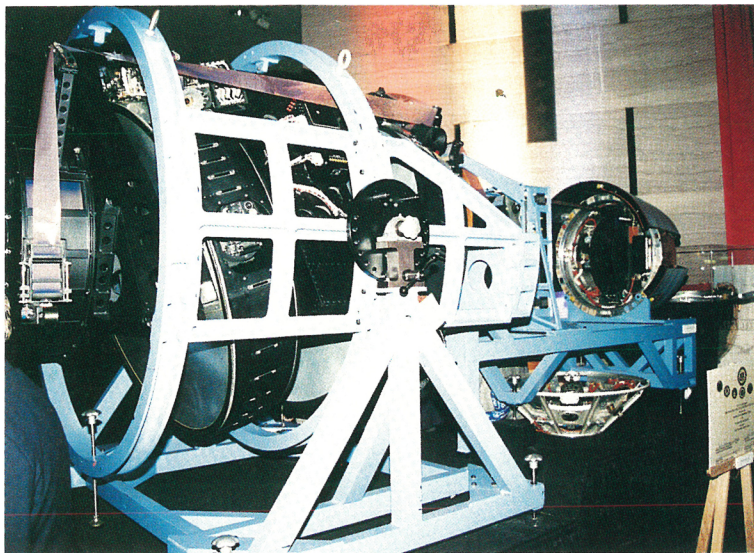


FIGURE 2. PAYLOAD. Two canted panoramic cameras can be seen at the left in this exhibition of an actual Corona payload. The 70 mm film passed through the cameras and was taken up on reels in the reentry capsules at the right. The structure used here for exhibition was replaced by the Agena spacecraft in actual flights.

system but would soon recommend that it be abandoned.

In an effort to develop budgetary support, the Air Force had started to reveal the Samos program. These revelations offended Eisenhower, who was determined not to confront the Soviets with the reality of our ongoing reconnaissance program. At Geneva in July 1955, Eisenhower had made his Open Skies proposal to allow reciprocal peaceful overflights of the US, Europe and the USSR, but it was rejected. Later, in his last few months in office, during the presidential campaign of 1960, he would refuse to contradict candidate John Kennedy's claim of a bomber and missile gap, even though he knew from U-2 and Corona photography that Kennedy was wrong. Eisenhower's goal was to win Soviet agreement that reconnaissance was legitimate and in our mutual interest. This policy was finally successful, and overhead reconnaissance is now enshrined in each of our strategic treaties as "national technical means."

Killian and Land made a strong recommendation to simplify and accelerate satellite reconnaissance activity. They wanted to start a new program based on film return from orbit. This program would focus on peacetime intelligence needs, rather than reconnaissance after a nuclear exchange. Eisenhower agreed. He was concerned with preventing nuclear war, not with waging it. Killian and Land wanted to streamline both the program and the technical management approach. They urged the President to assign the leadership for the new space system—to be called Corona—to the CIA. It would be led by the CIA's Richard Bissell, working with a small group of CIA and Air Force officers. This arrangement would emulate the successful partnership that had created the U-2 program.

They made this unusual suggestion for several reasons. The CIA had demonstrated an ability to keep tight security during the development phase of the U-2 project. It had shown a remarkable capacity for moving rapidly from concept to operations. Bissell and the CIA people were able to make and implement decisions quickly. In addition, they were quite open to suggestions from Land and the scientific community. It was Land who informed

Bissell that he had been given responsibility for the Corona program, thereby indicating the extraordinary influence that these scientists wielded.

Eisenhower approved a second reconnaissance program in 1959. The CIA and Bissell were authorized to develop a successor to the U-2 that would fly at three times the speed of sound. This manned system would complement the Corona satellite program. It would provide greater coverage flexibility and greater resolution than could be obtained from fixed Earth orbits. This remarkable airplane was called Oxcart and became operational in 1966. It was never used over the USSR, however, in view of the pledge that Eisenhower had made following the downing of Gary Powers's U-2 in May 1960. Follow-on versions of this airplane were operated by the Air Force as the SR-71 until early 1990.

Difficult design choices

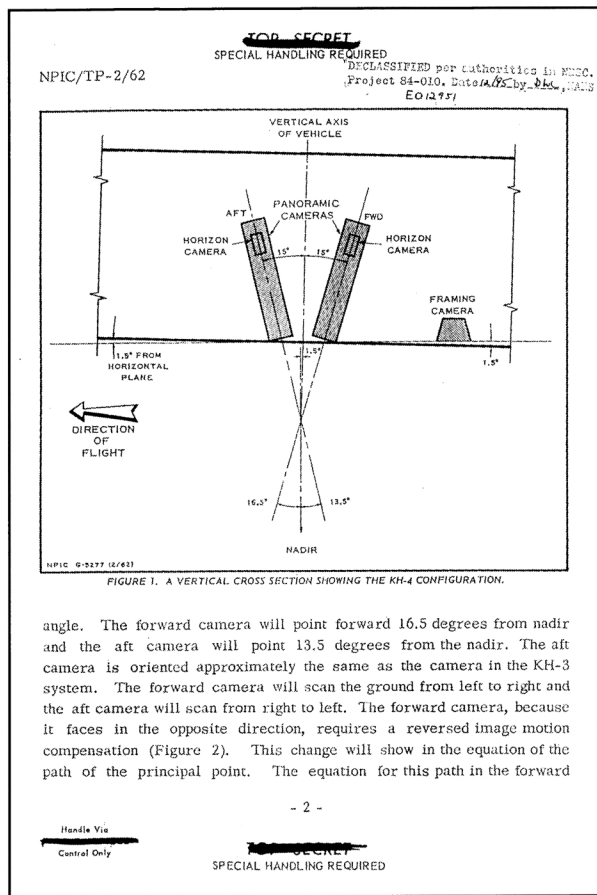
The presidential decision to proceed with the Corona program on this basis was made just eight weeks after the President's Foreign Intelligence Advisory Board submitted its report in early 1958. The goal was to achieve a photographic resolution of 25 feet or better in less than a year. It was to be

based on existing technology. Elements of other programs that promised early operational capability were to be transferred to it as needed. The initial thinking was that Corona would be an interim system. As it turned out, this interim system would become the backbone of our intelligence collection and national security policy planning for the next 12 years. The Samos program was canceled a few years later by the White House and the Department of Defense.

Bissell chose Air Force Brigadier General Osmand Ritland to be his deputy. The two had worked together on the U-2 and they had the utmost confidence in each other. A Corona program office was established in Los Angeles with about five Air Force officers under Colonel Lee Battle in early 1958. They were supported by a small group of CIA officers under John Parangosky, who reported directly to Bissell. The first task of Parangosky's group was to make the basic design choices and contractor selections that would permit the program to proceed.

The appropriate reconnaissance orbit had already been identified. It lay in a north-south plane oriented toward the Sun. The orbital inclinations chosen for each mission ranged from 60° to 100° (measured from the equator), depending on the desired coverage, but most missions would use values near 80°. The orbit would be close to circular, with a lowest height of approximately 100 miles. The highest altitude was fixed at 240 miles so that the orbital period would be almost exactly 90 minutes. As Earth turns beneath this trajectory, a new sunlit swath would be presented to each succeeding pass. The challenge was to place the Corona satellite in this orbit and recover film from it.

The planners decided to use the Thor intermediate-range ballistic missile as the first stage of the rocket combination that would place the payload in this orbit. The Thor had been flying successfully since 1957 and was then in large-scale production. It was a single-stage rocket that burned liquid oxygen and kerosene. Its single engine delivered 177 000 pounds of thrust at sea level. The Douglas Aircraft Co built this rocket and became a



charter member of the Corona team. It was being deployed to operational sites in England. Of greater importance was that a Thor launch training site was being established at Point Arguello in California that could fire directly south to establish a polar orbit—as could not be done from Florida because of range safety limitations.

The Thor would burn out at an altitude of 70 miles—well short of the reconnaissance orbit. An additional stage was thus needed to lift Corona. The Agena upper-stage vehicle had been in development at Lockheed for two years but had not yet flown. It was five feet in diameter and used a 16 000-pound thrust rocket engine that burned hydrazine and nitrogen tetroxide. Agena was the logical



FIGURE 3. SCHEMATIC DIAGRAM showing side view of the spacecraft with two Corona cameras positioned for stereoscopic coverage. The horizon cameras and downward-looking framing camera provided instantaneous measurements of the vehicle's attitude for later use by photointerpreters.

choice to provide the additional velocity, and Lockheed became the second team member.

Another decision was made concurrently that would cause substantial redesign of the Agena. Bissell and Ritland decided to combine the second stage and the orbital spacecraft. That meant that the camera and the film recovery systems would remain attached to the Agena for several days—and eventually for several weeks. The exhausted Agena would have to provide precise attitude control, battery power and thermal protection for the payload. The camera system now became the critical factor in determining the performance of the redefined Agena.

The most important decision facing Bissell and Ritland was the type of camera to be used. Rand and Lockheed had done some work on film recovery. Their approach used a spinning spacecraft to provide attitude control and camera scanning. It was based on a six-inch focal length camera, designed by Fairchild Instruments, but made no provision for orbital image motion compensation.

An experienced reconnaissance camera design team had recently left Boston University to form the Itek Corp. The team proposed a panoramic camera with a rotating telescope that would scan over a 70° arc at a constant angular rate.^{4,5} It was a mechanical design with almost no electronic components and was based on panoramic cameras the team had built previously for covert balloon flights. Their Corona design used a 24-inch focal length with an f-5 Tessar optical design. A narrow slit was positioned at the focal plane of the telescope. The film was held stationary on a cylindrical platen as the slit image was scanned over it. At an altitude of 100 miles, the rotating telescope would photograph an area 10 miles by 120 miles during a single scan. A new length of film would be moved forward along the platen during the telescope return cycle—and the process repeated. The system included a mechanical image motion compensation system set for the nominal speed and altitude. The telescope lenses were close to diffraction limited and required precision optical glass.

A fine-grain film was required to realize the resolution potential of the Itek camera. Eastman Kodak had developed such film for the U-2 program. For the Corona program, it developed an acetate-based film that was 70 mm wide and three thousandths of an inch thick. The film was relatively slow but gave 280 lines per millimeter over the entire field of view at high contrast. At two-to-one contrast, it gave 170 lines per millimeter. This compares with the best film used during World War II, which gave only 50 lines per millimeter.

There was initial concern that atmospheric scintillation might limit the resolution.⁶ Angle-of-arrival errors of one or two arc seconds are consistently measured by astronomical telescopes. At a slant range of 100 or 200 miles, the satellite could suffer image motion of three or four feet. It was soon found through analysis that image quivering would be considerably reduced if the receiver

FIGURE 4. AERIAL SNATCHING of a Corona film capsule by a C-119 aircraft near Hawaii. The capsule entered the atmosphere on a shallow trajectory and deployed its parachute at approximately 50 000 feet.

FIGURE 5. MOSCOW, photographed on 28 May 1970 from an altitude of approximately 100 miles. The enlargement of the Kremlin area shows a line of people waiting to view Lenin's tomb (the thin line at the lower left containing a 90° turn and a 45° turn).

were well removed from the turbulent region, rather than being immersed in it—as terrestrial telescopes are.⁷

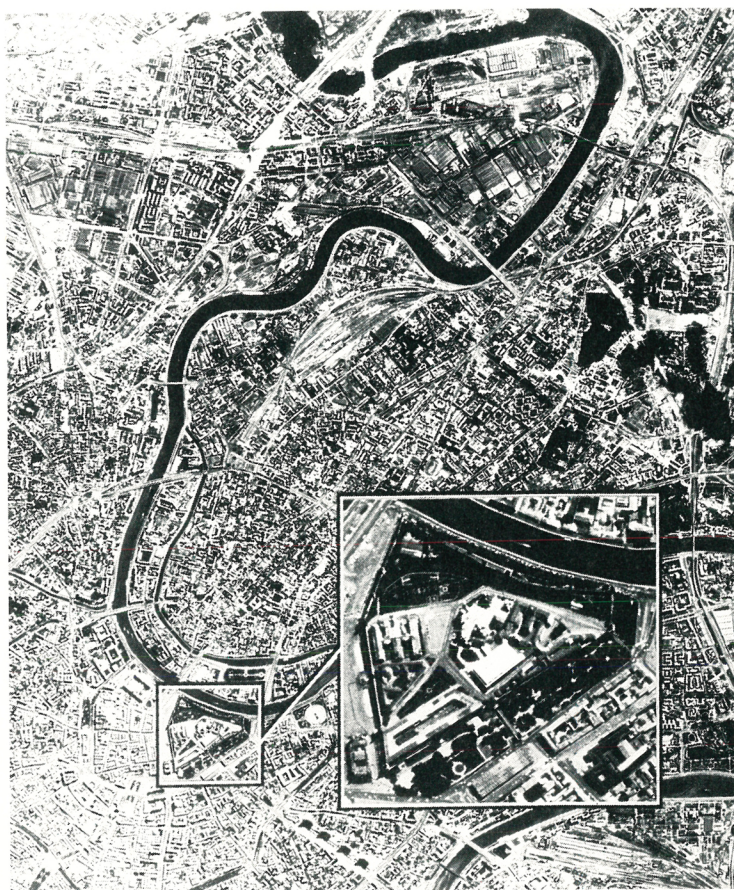
The camera decision shifted a large burden to the Agena spacecraft. It did so at a time when we had little experience in building such vehicles, and this inexperience accounts for many of the development problems. The panoramic camera design required that the spacecraft be stabilized around all three axes. An attitude control system using gyros, infrared horizon scanners and cold gas jets was developed and eventually gave an accuracy of 0.2° in the three degrees of freedom—pitch, roll and yaw. The precise orientation of the Corona cameras was reconstructed for each frame from the output of starfield and Earth-framing cameras and horizon photographs. Three decades of space missions used the basic Agena vehicle that was developed for Corona.

Film recovery

A capsule had never been returned from space when the program began, and Corona was the first to do so. The long-range missile program had already developed ablating nose cones that could withstand the enormous heat loads generated during ballistic reentry. It was clear from basic physics that the heating would be substantially less severe because the satellite return trajectory would be quite shallow compared to a ballistic path. The General Electric Co had developed ablation technology and was assigned the task of designing the film return capsule for Corona. The capsule's primary component was a take-up reel for the 70 mm film that would pass through the Itek camera.

At the end of the photographic mission, the Agena would be reoriented so that the capsule would point downward to make an angle of 120° with the orbital velocity vector. This angle was chosen to minimize the velocity impulse required for braking.⁸ The same choice ensured that the landing area would be insensitive to velocity alignment errors in the orbital plane. The capsule would then separate and spin up to provide attitude stability. A small solid fuel rocket would fire to provide a velocity impulse of 1300 feet per second. That would be enough to send the capsule back to the surface after traveling almost a quarter turn around Earth.

To begin the recovery operation, a microwave command signal would be sent to the Agena as it came over the North Pole. If all worked according to plan, the capsule would impact near Hawaii in an area measuring 150 by 400 miles. The maximum heating rate during reentry would occur at 350 000 feet, where the ablation heat shield would reach temperatures of 4000 °F. A parachute would deploy when the capsule reached 50 000 feet and slow the descent to about 30 feet per second. A fleet of Air Force C-119 aircraft would be deployed from Hawaii to air snatch the descending capsule. These planes would each tow long nylon loops with which the air



crews would try to snare the parachute and then reel it into the aircraft. Ships and helicopters would also be deployed to recover the capsule if the aircraft missed it and it fell into the sea.

Development problems

A three-page work statement dated 25 April 1958 reflects these daring decisions. The subsystems were rapidly built by engineers and technicians working under pressure comparable to wartime conditions. The cameras, film and reentry capsules were integrated with the Agena at a special facility near Palo Alto, California. The completed spacecraft was then taken to Vandenberg Air Force Base, where it was mated to the Thor and Agena rocket stages.

The first mission was ready for launch on 28 February 1959, less than ten months after the decision to proceed. It failed because the Agena ignited prior to launch, causing the Thor to fail. The next eleven missions were also failures. It is important to remember that the country had almost no experience in developing satellites before 1958. The pioneering role fell to the Corona program. In our current state of technical accomplishment, we tend to forget how inexperienced we all were in those early days. The Vanguard rocket developed for the International Geophysical Year in 1958 had been a national embarrassment. Thor and Atlas had both gone through serious problems when they began, and Titan was then in the midst of its development troubles. The Centaur upper stage was encountering enormous problems, and Ranger missions to the Moon were frustrating failures.

It also proved to be a difficult task to cause the capsules to land in the planned recovery area. On two



FIGURE 6. THE PENTAGON building near Washington, DC, as photographed by Corona on 25 September 1967.

apparently successful flights in the first year, the capsules fell far outside the recovery zone and were not recovered: one fell in the Spitsbergen island group north of Norway, and the other in Antarctica. We found that we still had a great deal to learn about snagging the parachutes of descending film capsules. In addition, the acetate-based film became embrittled in space and broke several times. Fortunately, Eastman Kodak had developed a polyester-based film that corrected this deficiency.

One of the greatest problems for the Corona team was the pressure to continue launching at a rapid pace. This was driven by the extraordinary urgency to get firm evidence of Soviet missile deployments—evidence that could only come from space. During the first year, we launched one mission each month (on average), despite major technical problems. This short interval did not give us enough time to analyze and fix problems before the system was launched again. By contrast, the space shuttle was grounded for almost three years after the Challenger accident in 1986. That luxury was not available to the men and women working on the Corona program.

Our problems were compounded by the fact that the program had a razor-thin weight margin and could carry very little instrumentation. That meant that the engineers usually did not have enough diagnostic data to correct the problems with confidence. Each time the choice was simple: carry film or carry instruments. We almost always chose film. What is remarkable is that Bissell and Ritland pressed on in spite of these failures—and that Eisenhower continued to support them.

Impact on intelligence

Corona 13 was launched on 10 August 1960 and became the first completely successful flight. Unfortunately, it carried no film because the program office had decided to fly a full load of diagnostic instruments. Corona 14 was launched a week later and returned 20 pounds of film after 17 passes over the USSR and China. This mission produced a cornucopia of data and gave more coverage than all the prior U-2 flights combined. For policymakers and intelligence analysts alike, it was as if an enormous floodlight had been switched on in a darkened warehouse. Corona photography quickly assumed a decisive role in the cold war analogous to that of the breaking of German

cipher machine codes in World War II.

The CIA director's National Intelligence Estimates were the basis for defense planning and force structure decisions. Prior to Corona's success, those estimates were surrounded by uncertainty and disagreement. With very little hard data, it was possible for hawks to argue that the Soviet threat was enormous, while the doves could maintain that it was trivial. This situation changed completely as satellite photography began to pour in. Now there could be little debate about the number of Soviet bombers and missiles. Six months before the first successful mission, the National Intelligence Estimates predicted that there would be 140 to 200 Soviet ICBMs deployed by 1961. That estimate became 10 to 25 soon after the

first flight in February 1959. President Kennedy realized that the US was well ahead and had literally frightened itself through ignorance. Satellite photographs quickly reduced the range of debate and uncertainty. Perhaps just as important was the fact that anyone could understand and evaluate the photographs. Analysts and presidents alike could see the large facilities and make their own judgments.

As the system began providing monthly coverage, the photointerpreters went into complete overload. This community had been sized to cope with sporadic U-2 flights. The CIA moved quickly to expand the cadre of photointerpreters. We consolidated the existing capabilities in a new National Photointerpretation Center in Washington, DC. We began the development of automatic pattern recognition machines to help the photointerpreters do their job. It is a great satisfaction to me that these machines are now being used by the medical community to interpret mammograms.

Improvements

The first two years of Corona development were marked by great daring, repeated disappointments and finally by extraordinary success. Having risked so much at the outset, the program then settled into a pattern of gradual improvement. Performance of the Thor and Agena rockets was steadily increased by extending the tanks and adding strap-on solid fuel rockets. The larger payload capability was used to increase the film load and extend the time in orbit to ten days. When the lifting capability of the rocket stages was great enough, a second camera was added to provide stereoscopic coverage.

The basic camera was improved by going to a Petzval f-3.5 lens design. The attitude control capability of the Agena improved with time. Through these upgrades, the resolution was improved from 25 feet to 6 feet. The active control system was augmented by horizon, star and framing cameras that recorded the instantaneous vehicle attitude for use by the photointerpreters. Color and infrared film were tried, but they seemed not to increase the intelligence value of the photography.

Recovery techniques were perfected, and it became a rare event when a film capsule was lost. The number of capsules on each mission increased from one to two so

that a load of film could be returned and processed while the satellite continued taking pictures in orbit.

A major challenge to the Corona program occurred in 1963. Some of the returned film was completely exposed—apparently by a bright source. We judged that this was caused by corona discharge in the satellite. I persuaded Sidney Drell to take leave from Stanford University to lead a team of engineers and scientists to address this problem. With Itek engineers, they traced the problem to outgassing from the rubber rollers that transported film through the camera. By vacuum testing and careful selection of rollers, the problem was solved within a year.

That was the first time that a younger, second generation of scientists became deeply involved in our activities. Drell, Richard Garwin, William Perry, Joseph Shea and Frank Lehan went on to make enormous contributions to all of our reconnaissance programs during the next three decades.

Next steps

As we became comfortable with Corona operations, the CIA began to look ahead. It was apparent that the photointerpreters were having difficulty finding strategic targets in the vast amount of 70 mm film that was arriving. I asked the Drell group to examine this problem, and I put two questions to it: What resolution do the photointerpreters need to find and identify strategic installations in broad area coverage; can Corona be improved to provide that level, or must we begin a new system?

We approached these questions by preparing simulated satellite photographs from high-resolution U-2 coverage and giving them to the photointerpreters to see how recognition varied with resolution. The experiments confirmed my impression that a substantial improvement in resolution was needed. The Drell group judged it unlikely that we could push the Corona system to that new level by further improvements. Corona's basic design had inherent limits, and we had reached them.

Vulnerability

From my first days in government service, we all worried a great deal about the vulnerability of Corona. We recognized that it was an easy matter for the Soviets to locate these satellites and predict their orbits. We were obliged by international agreement to notify the United Nations of each launch—although not its purpose. The Agena spacecraft transmitted four microwave signals on frequencies ranging from 137 to 2500 MHz. These signals carried telemetry data and were also used by our ground stations to track the spacecraft. It was clear that the Soviets could also track these missions using the same signals and probably knew their orbits almost as well as we did.

It is an easy matter to destroy satellites in low Earth orbit if there is an incentive to do so.⁹ The US established two antisatellite systems in the Pacific Ocean in 1963, and kept them in operation for almost ten years. One was based on the Nike-Zeus ABM system and was deployed on Kwajalein, an island in the western Pacific. The other used the Thor intermediate-range ballistic missile system on Johnston Island about 700 miles southwest of Hawaii. In both systems, the plan was to wait until a Soviet satellite passed reasonably close to these islands and then rise to destroy it with nuclear warheads—if the command was given. The Soviets were deploying nuclear-tipped ABMs at dozens of sites around Moscow and had several test launchers near Lake Balkhash in what is now Kazakhstan. We recognized that it would be a simple matter for these systems to eliminate Corona. Had they done so, we would have had to conduct our affairs in almost total ignorance of the Soviets' activities—as we did

prior to 1960.

The destruction of a low-altitude satellite does not require nuclear weapons. Because such vehicles travel in Earth orbit at speeds of approximately 17 000 miles per hour, it is only necessary to stand in their path to destroy them. Our apprehension was increased in 1967, when the Soviets began to flight test a co-orbital antisatellite system that could do just that. It was successful in 11 of 22 tests against orbital targets that they put up.

A wide range of defensive measures were examined. We considered inflating and deploying decoy balloons for the primary spacecraft. This strategy suffered a fundamental flaw because it was soon evident that the decoys would periodically reunite with the satellite. We also considered orbit adjust maneuvers that would change the arrival times over defensive installations. As a practical matter, this approach would have required the satellite to expend fuel and make mechanical changes in the camera settings. To make a meaningful orbit change, one would have to use large amounts of fuel because the basic orbit speed is so great. Such corrections could be made only once or twice, and we judged that they would not defeat a determined attack.

These proposals were not implemented, primarily because they required a great deal of payload weight. We opted each time for increased film loads and prayed that Corona would not be attacked. As the Soviets developed their own reconnaissance satellites, both parties saw benefit in avoiding space warfare. A climate of mutual forbearance set in, which now serves both parties extremely well.

Perspective

Corona photographs provided the backbone of US intelligence capability for 12 precarious years. In that time, it made an extraordinary contribution to world stability. It gave American presidents poise and confidence when that was most needed. It enabled arms control treaties to be negotiated and monitored with confidence—treaties that are now reducing nuclear and conventional arsenals dramatically.

When the US government sees fit to reveal other reconnaissance systems developed by this nation, the public will learn of space achievements every bit as impressive as the Apollo Moon landings. One program proceeded on national television; the other in utmost secrecy. One steadied the resolve of our people; the other steadied the resolve of American presidents.

I based this article on my keynote address at a Washington, DC, conference, Piercing the Curtain: Corona and the Revolution in Intelligence, sponsored by George Washington University and the CIA Center for the Study of Intelligence, 23 May 1995.

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