CORONA Reconnaissance Satellite

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The CORONA program came at a time when classified optics programs were in their steepest ascent toward a mission to literally save the world. But very few people realized it at the time because it was among the most classified of all classified programs. Outside of a team of fewer than 100 scientists, at one point only six people, including President Eisenhower, were aware of the work that together with the U2 surveillance plane helped save the world from nuclear war. Significantly, a single person was behind the success of both CORONA and the U2 missions: Richard Bissell of the CIA.

Initiated just weeks after the Soviet *Sputnik* launch, CORONA was at the cutting edge of technology and a remarkably visionary program. It anticipated that the high-altitude U2 could be brought down, as it would be in 1960. Its crucial role was to cast the light of knowledge onto the dangerous shadows of speculation about Soviet capabilities. At one point, advisors told Eisenhower that the U.S. needed 10,000 nuclear warheads to catch up. The U2 and CORONA together provided hard evidence that if there was a "missile gap," it was the Soviets who were behind. The first successful CORONA mission acquired ten times more information than all of the preceding U2 missions combined. Eisenhower's visionary program was a credit to his presidency, and kept President Kennedy from overreacting to the Cuban missile crisis in 1962.

The saga of CORONA has been the subject of a number of good books since its declassification in 2004. A major reference for this article was *ITEK and the CIA* [1], which offers a substantial, factual account of the CORONA program. The most readable history of CORONA, which covers many of the technical and operational issues, is *Eye in the Sky: The Story of the CORONA Spy Satellites* edited by Day, Logsdon, and Latell [2], in the Smithsonian History of Aviation Series. Another important resource for this essay was a plenary talk given at the 2004 SPIE annual meeting by (the late) Robert S. Hilbert, one of the principal optical engineers on CORONA for nearly a decade before becoming the leader of Optical Research Associates. The author worked with him for nearly 20 years.

CORONA, like the U2, proceeded from concept to flight hardware in a matter of months, an incomprehensible pace today. The multidisciplinary team of engineers and scientists were armed primarily with slide rules and engineering judgment, and they had only limited computer simulation capabilities. But they were unencumbered by any significant management or budget constraints and were driven by genuine personal urgency to move ahead at a pace that was perhaps matched only by the earlier U2 program at the Burbank Skunk Works. The engineering team, fortuitously, had been together for some years. Nearly all had worked at a reconnaissance research facility at Boston University. The university was in a financial crisis when Eisenhower commissioned CORONA and was disbanding the reconnaissance group, which was quickly bought by the newly formed Itek Corporation, formed with funding from David Rockefeller.

Rockefeller was an outspoken conservative who decided that if he would not implement his vision of a better world politically, he would create it by backing key technologies that enabled his goals. He was a visionary who saw that gaining knowledge of the unknown was a key to ensuring the future. At the time, Eisenhower was crippled by having no information at all about vast expanses of adversarial countries. This lack of knowledge led to speculation that potential adversaries had vast arsenals, as well as strong pressure from the military, the press, and the public to arm the U.S. well beyond its means. Eisenhower made a key decision, that knowledge at any monetary cost was the best option.

Rockefeller's role was vital because the president could not directly ensure that Itek had the financial resources needed for the program. Because Eisenhower's key military advisors knew nothing about CORONA, he was continually challenged as being indecisive in ways that were clearly rational in light of the super-secret project. As one of the six people briefed on the program outside of Itek, Rockefeller understood this. However, he was the only Rockefeller briefed, and Itek needed so much financing that he had to involve his brothers. This led to some suspense in the story of Itek, but in the end all the Rockefellers invested—and reaped the financial benefits by a timely exit from Itek before Perkin-Elmer won a vital contract for the follow-on Hexagon ("Big Bird") program.

Edwin Land, the founder of Polaroid, was a second key technology advisor and an important link between the optics community and the president. At a time when the Air Force was pushing for a first-of-its-kind crash program in electronic imagery from space, it is likely, but unverified, that Land kept the CORONA mission firmly based in film (although the film was to come from Kodak). Although the program was Eisenhower's highest priority, its classification level made it impossible to get priority access to new technology, in particular a critical polyester base film from Kodak. After the project stalled because it lacked the special film they needed, Bissell quietly intervened and a large batch suddenly arrived.

The exposed film had to be returned to Earth for processing, so it was jettisoned in a capsule that was supposed to be caught in the air by a C-130 aircraft. To make sure the film did not fall into the wrong hands, the capsules had salt plug seals that dissolved in an hour to drop them to the bottom of the sea. Only the film returned to earth, so each mission needed a new camera. The logistics of this were staggering.

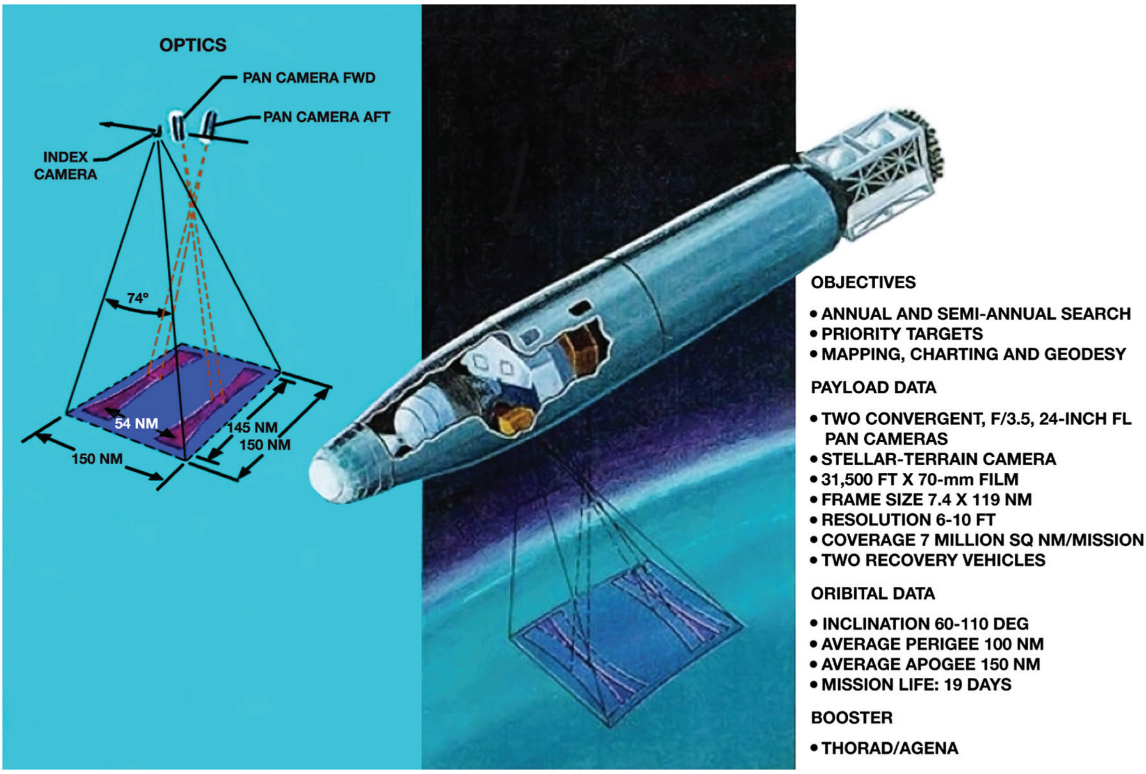
The CORONA program became the definition of perseverance, determination, and perhaps desperation. The crash program went through a long series of failures, often with the rocket simply blowing up on the launch pad, a problem not related to CORONA. That might be expected at the beginning of the space age, but for a year it set a grueling pace for the scientists. Bob Hilbert would typically arrive at the office between 10 a.m. and noon for technical meetings and exchanges and then work through to midnight. At midnight, he would put on his optics engineer hat and work on computer simulations until 4 a.m. because the computer time was too expensive at other hours. His wife always had his dinner prepared when he arrived, at 4:15 a.m., seven days a week.

The stakes were raised after the Soviet Union shot down a U-2 over Siberia on 1 May 1960, stopping flights that had been the best source of surveillance data. On 10 August, the fourteenth CORONA launch successfully orbited a capsule carrying an American flag, but the recovery aircraft flew in the wrong direction. Fortunately, a Navy ship was able to retrieve the capsule. The next launch came on 18 August, carrying a camera that operated successfully and ejected film that was successfully recovered.

The composite graphic in Fig. 1 gives a good overview of the CORONA equipment. Instead of stabilizing the capsule by spinning it in orbit, which would make photography difficult, Itek scientists stabilized it with small microjets. The camera itself needed to move back and forth in a pendulum-like motion to image from side to side. These requirements prevented use of the Fairchild camera used for imaging in the Korean War, so Itek had to design their own based on earlier ideas for a panoramic camera for imaging large swaths of the ground by sweeping in a cross-track direction as the satellite orbited.

The chosen orbit was a north–south one synchronous with the sun to provide maximum high-latitude coverage during daylight. Initial designs used an oscillating lens to focus the image onto a curved platen carrying the photographic film. Traditional aerial photography generally used long focal lengths to produce large-scale images to record sufficient detail with the limited resolution of photographic film. However, the size and weight restrictions of early satellite systems limited the focal length and the amount of film that could be carried to orbit. CORONA had to achieve very high resolution in a compact system constrained by film handling and dynamic limitations.

Robert Hopkins of the Institute of Optics suggested a Petzval-type design to meet the camera resolution requirements. Itek engineers directed by Walter Levison, Frank Madden, and Dow Smith generated a novel Petzval design that mounted primary and large-aperture imaging components in a constantly rotating lens barrel and put the lower-tolerance field flattening components near the focal surface in a lightweight oscillating arm that defined the image location. These two assemblies operated

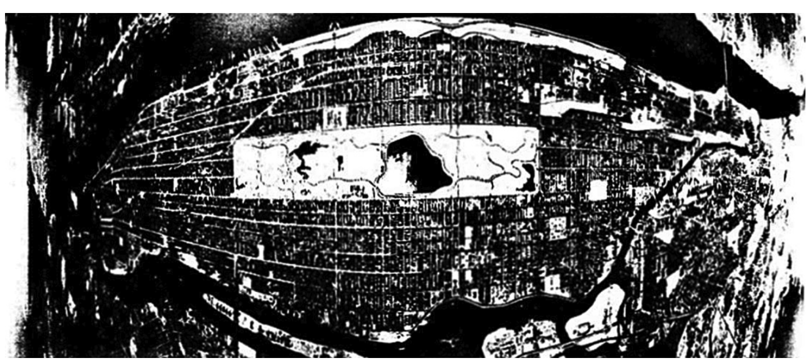


▲ **Fig. 1.** A pair of convergent f/3.5 cameras produce stereo images of the ground on 70-mm film, with each frame covering 7.4 by 119 nautical miles. (Courtesy of Bob Hilbert, Itek.)

synchronously to "wipe" the image across the photographic film. The film was advanced when the lens was rotating in a non-image collecting part of the cycle and was dynamically located relative to the lens just at the time of exposure by rollers attached to the oscillating field flattener assembly.

The result was a minimum-weight camera that could fit across the width of the spacecraft and allowed the inclusion of two cameras to provide stereo coverage of the entire imaging swath. The optical components also needed to exhibit appropriate lateral shifts during the panoramic scan to provide image motion compensation and reduce along track blur in the recorded image. Additional optics recorded stellar index images on the film to aid geo-location of targets. The result was a remarkable synthesis of optical, mechanical, and electrical systems that were the most complicated, and eventually reliable, systems of their kind to be incorporated in a spacecraft at the time.

Figure 2 shows a test exposure taken from an aircraft flying over Manhattan, which illustrates the strong distortion of the wide-panorama photos. One of Bob Hilbert's key responsibilities was the optical design and manufacture of the "rectifier" lens based on a concept credited to Claus



▶ **Fig. 2.** Stereo cameras used in Corona have high resolution combined with large intrinsic distortion, shown in this image of Manhattan taken from 10,000 feet. (Courtesy of Bob Hilbert, Itek.)

Aschenbrenner. The idea was to construct a lens that exactly reverses the distortion of the taking lens, a very effective approach still used in cinematography. The rectifier lens imaged returned film onto a second film image that was corrected for panoramic scan distortion.

Once it was finally successful, CORONA went on 85 successful missions, the last launched in 1972. Its career, and that of Itek and Itek's scientists and engineers, was ended somewhat unceremoniously when the follow-on program was canceled in what was primarily a political battle and passed on to Perkin-Elmer, who successfully developed a wide area photographic imaging system with a new name, Hexagon, nicknamed "Big Bird." Itek did later develop a precision large-format mapping camera which flew along with many of the Hexagon missions.

CORONA optics presented challenges, but the complex film transports represent impressive engineering feats. The preceding article by Phil Pressel describes the film transports used in the larger Hexagon program, sort of a CORONA on steroids.

These pioneering optical systems are now on display. You can view a CORONA camera at the National Air and Space Museum in Washington, D.C. Samples of the Hexagon and GAMBIT systems are viewable at the National Museum of the U.S. Air Force in Dayton, Ohio.

References

1. J. E. Lewis, *Spy Capitalism: Itek and the CIA* (Yale University Press, 2002).
2. D. A. Day, J. M. Logsdon, and B. Latell, *Eye in the Sky: The Story of the Corona Spy Satellites* (Smithsonian Institution Press, 1998).