4 January 1971

CORONA: The First Photographic Reconnaissance Satellite

The U-2, which began operating in the fall of 1956, was expected to have a relatively short operational life in over-flying the Soviet Union--perhaps no more than a year or two. That expectation was based less on the likelihood of the Soviets perfecting a means of shooting it down than on their ability to develop a radar surveillance network capable of reliably tracking the U-2. With accurate tracking data in hand, the Soviets could file diplomatic protests with enough evidence in support of them to lead to political pressures to discontinue the overflights. As it turned out, we had misjudged the performance characteristics and deployment pattern of the Soviet air surveillance network. Their radars promptly acquired and continuously tracked the very first U-2 flight over Soviet territory. The Soviets filed a formal protest within days of the incident, and a standdown was ordered.

For nearly four years, the U-2 ranged over much of the world, although only sporadically over the Soviet Union. The effectiveness of the Soviet radar network was such that each flight risked another protest and another standdown. Clearly, some means had to be found for accelerating the initial operational capability of a less vulnerable successor to the U-2. Fortunately, by the time

Francis Gary Powers was shot down near Sverdlovsk on 1 May 1960 (fortunate for the intelligence community, that is--not for Powers), an alternative means of carrying out photographic reconnaissance over the Soviet Union was approaching operational readiness. On 19 August 1960, just 110 days after the downing of the last U-2 overflight of the Soviet Union, the first successful air catch was made near Hawaii of a capsule of exposed film ejected from a photographic reconnaissance satellite that had completed seven passes over denied territory and 17 orbits of the earth. The feat was the culmination of four years of intensive and often frustrating effort to build, launch, orbit, and realize an intelligence product from a camera-carrying satellite.

At about the time the U-2 first began overflying the Soviet Union in 1956, the U.S. Air Force was embarking on the development of a strategic reconnaissance weapons system employing orbiting satellites in a variety of collection configurations. The program, which was designated WS-117L, had its origins in 1946 when a requirement was placed on the RAND Corporation for a study of the technical feasibility of orbiting artificial satellites. The first real breakthrough had come in 1953 when the USAF Scientific Advisory Board reported to the Air Staff that it was feasible to produce relatively small and light-weight thermonuclear warheads. As a result of that report, the ATLAS ICBM program was accorded the highest priority in the Air Force.

Since the propulsion required to place a satellite in orbit is of the same general order of magnitude as that required to launch an ICBM, the achievement of an ICBM-level of propulsion made it possible to begin thinking seriously of launching orbital satellites. Accordingly, General Operational Requirement No. 80 was levied in 1955 with the stated objective of providing continuous surveillance of pre-selected areas of the world to determine the status of a potential enemy's war-making capacity.

The Air Research and Development Command, which had inherited the RAND study program in 1953, assigned the satellite project to its Ballistic Missile Division. The development plan for WS-117L was approved in July 1956, and the program got under way in October 1956 with the awarding of a contract to the Lockheed Aircraft Corporation for the development and testing of the system.

The planning for WS-117L contemplated a family of separate systems and subsystems employing satellites for the collection of photographic, electronic, and infrared intelligence. The program, which was scheduled to extend beyond 1965, was divided into three phases. Phase I, the THOR-boosted test series, was to begin in November 1958. Phase II, the ATLAS-boosted test series, was scheduled to begin in June 1959 with the objective of completing the transition from the testing phase to the operational phase and of proving the capability of the ATLAS booster to launch heavy loads into space. Phase III, the operational series, was to begin in March 1960 and was to consist of three progressively more sophisticated systems: the Pioneer version (photographic and electronic), the Advanced version (photographic and electronic), and the Surveillance version (photographic, electronic, and infrared). It was expected that operational control of WS-117L would be transferred to the Strategic Air Command with the initiation of Phase III.

It was an ambitious and complex program that was pioneering in technical fields about which little was known. Not surprisingly, it had become apparent by the end of 1957 that the program was running behind schedule. It also was in trouble from the standpoint of security. The U-2 program was carried out in secret from 1956 until May 1960--not from the Soviet Government, of course, but the Soviets chose to allow the program to remain a secret from the general public (and from most of the official community) in preference to publicizing its existence and thereby admitting that they lacked the means of defending their air space against the high-flying U-2. WS-117L was undertaken as a classified project, but its very size and the number of people involved made it impossible to conceal the existence of the program for long. The press soon began speculating on the nature of the program, correctly identifying it as involving military reconnaissance satellites, and referring to is as BIG BROTHER and SPY IN THE SKY. The publicity was of concern, because the development of WS-117L was begun in a period when the international political climate was hostile to any form of overflight reconnaissance.

It was against this background that the President's Board of Consultants on Foreign Intelligence Activities submitted its semi-annual report to the President on 24 October 1957. The Board noted in its report that it was aware of two advanced reconnaissance systems that were under consideration. One was a study then in progress in the Central Intelligence Agency concerning the feasibility of a manned reconnaissance aircraft designed for greatly reduced radar cross-section; the other was WS-117L. The Board recommended that an early review be made of new developments in advanced reconnaissance systems to ensure that they were given adequate consideration and received proper handling in the light of then-existing and future intelligence requirements. The Executive Secretary of the National Security Council on 28 October notified the Secretary of Defense and the Director of Central Intelligence that the President had asked for a joint report from them on the status of the advanced systems. Secretary Quarles responded on behalf of himself and Mr. Dulles on 5 December with a recommendation that, because of the extreme sensitivity of the subject, details on the new systems be furnished through oral briefings.

As a consequence of that proposal, which evidently was accepted, there are no written records in CIA's Project CORONA files bearing dates between 5 December 1957 and 21 March 1958. It is clear, however, that major decisions were made and that important actions were undertaken during the period. In brief, it was decided that the photographic subsystem of WS-117L offering the best prospect of early success would be separated from WS-117L, be designated as Project CORONA, and be placed under a joint CIA-Air Force management team--an approach that had been so successful in covertly developing and operating the U-2.

The nucleus of such a team was then constituted as the Development Projects Staff under the direction of Richard Bissell, who was Special Assistant to the DCI for Plans and Development. Bissell was designated as the senior CIA representative on the new venture, and his Air Force counterpart was Brigadier General Osmund Ritland, who, as Colonel Ritland, had served as Bissell's first deputy in the early days of the Development Projects Staff and was then Vice Commander of the Air Force Ballistic Missile Division.

Bissell recalls that he first learned of the new program and of the role intended for him in it "in an odd and informal way" from Dr. Edwin Land with whom he had worked on the development of the U-2 reconnaissance system and who had come to head a panel of technical consultants informally known as the Land Panel. Bissell also recalls that his early instructions were extremely vague: that the subsystem was to be split off from WS-117L, that it was to be placed under separate covert management, and that the pattern established for the development of the U-2 was to be followed. One of the instructions, however, was firm and precise: none of the funds for the new program were to come from monies authorized for already approved Air Force programs. This restriction, although seemingly clear at first glance, later led to disagreement over its interpretation. CORONA management expected that the boosters already approved for the THOR test series of WS-117L would simply be diverted to the CORONA program; this proved not to be so. As a consequence, CIA had to go back to the President with an admission that the original project proposal had understated the estimated cost and with a request for more money.

Roughly concurrent with the decision to place one of the WS-117L subsystems under covert management, the Department of Defense realigned its structure for the management of space activities. The Advanced Research Projects Agency (ARPA) was established on 8 February 1958 and was granted authority over all military space projects. The splitting off of CORONA from WS-117L was accomplished by an ARPA directive of 28 February 1958 assigning responsibility for the WS-117L program to the Air Force and ordering that the proposed WS-117L interim reconnaissance system employing THOR boost be dropped.

The ARPA directive ostensibly cancelling the THOR-boosted interim reconnaissance satellite was followed by all of the notifications that would normally accompany the cancellation of a military program. The word was passed officially within the Air Force, and formal contract cancellations were sent out to the prospective suppliers. There was much furore when the cancellations went out: contractors were furious over the suddenness of the action; Air Force personnel were thunderstruck at the abandonment of the WS-117L photographic subsystem that seemed to have the best chance of early success. Subsequent to the cancellation, very limited numbers of individuals in the Air Force and in the participating companies were cleared for Project CORONA and were informed of the procedures to be followed in the covert reactivation of the cancelled program.

Although CORONA was removed from WS-117L and placed under separate management as a covert activity, the original intent was to disguise its real purpose by concealing it as an experimental program within the first phase of WS-117L. This permitted overt procurement of the necessary boosters, second stages, and hardware associated with the biomedical cover launches. It also provided an explanation for the construction of launch and ground control facilities. Only the program-peculiars associated with the true photographic reconnaissance mission had to be procured covertly.

After Bissell and Ritland had worked out the arrangements for the overt cancellation and covert reactivation of the program, they then began tackling the technical problems associated with the design configuration they had inherited from WS-117L. The subsystem in point contemplated the use of the THOR IRBM as the first stage booster and, as a second stage, a Lockheed-modified rocket engine that had been developed by Bell Aircraft for take-off assist and auxiliary power applications in the B-58 HUSTLER bomber. It was referred to as the HUSTLER engine during the development phase of CORONA but soon came to be known as the AGENA--the name it bears today. The plan called for spin stabilization of the pod containing the payload, with the camera scanning as the pod rotated. The camera was to have a focal length of six inches, without image motion compensation, and would require the use of fast film. The film was to be fed into a capsule, which would be recovered from orbit. Ground resolution was expected to be poor because of the short camera focal length and the grainy photography yielded by fast film. The contractors who had been working on the subsystem design were Lockheed on the space vehicle, General Electric on the re-entry body, and Fairchild on the camera.

The initial intent of the CORONA managers was to proceed with the configuration described above. As will be seen later, this was not the configuration that was finally chosen. The ground resolution attainable by it would not meet intelligence needs, and by late March 1958 major complications had arisen in the technical design of the Fairchild camera.

A three-day conference was held in San Mateo, California, in late March among representatives of CIA, Air Force Ballistic Missile Division, Lockheed, General Electric, and Fairchild. Their discussion revealed that, while work was going forward, the design was far from complete. The senior Lockheed representative reported that they had investigated the possibility of building a satellite vehicle shaped like a football, a cigar, or a sphere. They had finally decided, for the original drawings at least, on a football-shaped pod slightly elongated at each end to correct the center of gravity. Discussion got onto the need for immediate contractual arrangements with the various suppliers. Bissell remarked that he was "faced with the problem at present of being broke" and would need estimates from all of the suppliers as soon as possible in order to obtain the necessary financing to get the program under way. The suppliers agreed to furnished the required estimates by the following week.

The project quickly began taking formal shape following that meeting. Within a span of about three weeks, approval of the program and of its financing was obtained, and the design of the payload configuration evolved into a concept quite different from the spin-stabilized pod. In late March and early April, interest shifted to a competitive design submitted by the ITEK Corporation, (1) which proposed a longer focal length camera scanning within an earth-center stabilized pod. Bissell recalls that he personally decided in favor of the ITEK design, but only after much agonizing. The decision was plainly a difficult one to make, because it involved moving from a proven and relatively simple method of stabilization to one that was untried and was technically more difficult to accomplish. Nor, for that matter, was the decision taken in a single step.

Bissell's first project proposal, which was completed on 9 April 1958, requested approval for concurrent development of both the Fairchild and the ITEK systems, with the Fairchild configuration becoming operational first and the ITEK configuration being developed as a follow-on system. Within two days, however, Bissell had made the final decision to abandon the Fairchild spin-stabilized configuration entirely. He rewrote the project proposal, taking note of the earlier configuration and giving his reasons for favoring the ITEK approach (principally the better resolution attainable, the lower overall cost, and the greater potential for growth). The proposal was rewritten a second time, retaining the ITEK configuration but raising the cost estimate from $20 million to $31 million. Of the total estimated cost, $24 million represented "a rather arbitrary allowance" for 12 each THOR boosters and Lockheed second stage vehicles and was to be financed by ARPA through the Air Force. The remaining $7 million was for covert procurement by CIA of the pods containing the reconnaissance equipment and the recoverable film cassettes.

The final project proposal was forwarded to Brigadier General Andrew J. Goodpaster, the President's Staff Secretary, on 16 April 1958 after having been reviewed by Mr. Roy Johnson and Admiral John Clark of ARPA; Mr. Richard Horner, Assistant Secretary of the Air Force for Research and Development; Brigadier General Osmund Ritland, Vice Commander, Air Force Ballistic Missile Division; and Dr. James Killian, Special Assistant to the President for Science and Technology. The proposal was approved, although not in writing. The only original record of the President's approval reportedly was in the form of a handwritten note on the back of an envelope by General Cabell, then Deputy Director of Central Intelligence.

Although it may have been the original intent that CORONA would be administered in a manner essentially the same as that of the U-2 program, it actually began and evolved quite differently.

It was a joint CIA-ARPA-Air Force effort, much as the U-2 was a joint CIA-Air Force effort, but it lacked the central direction that characterized the U-2 program. The project proposal described the anticipated administrative arrangements, but it fell short of clarifying the delineation of authorities. It noted that CORONA was being carried out under the authority of ARPA and CIA with the support and participation of the Air Force. CIA's role was further explained in terms of participating in supervision of the technical development, especially as regards the actual reconnaissance equipment, handling all covert procurement, and maintenance of cover and security. The work statement prepared for Lockheed, the prime contractor, on 25 April 1958 noted merely that technical direction of the program was the joint responsibility of several agencies of the Government.

The imprecise statements of who was to do what in connection with CORONA allowed for a range of interpretation. The vague assignments of responsibilities caused no appreciable difficulties in the early years of CORONA when the joint concern was primarily with producing as promised, but they later became a source of severe friction between CIA and the Air Force over responsibility for conducting the program. Not only was it unclear as to who was to do what, it is difficult, in retrospect, even to discover who actually did what. An officer who was with the program, in preparing a brief historical summary of it in early 1965, noted that: "It appears somewhat mixed right now as to exactly who was doing detailed supervision of the cameras and associated equipment." Bissell, upon reading the paper recently, commented that if he had been the author he could have written only that this was a matter that he and General Ritland had handled together. He then expanded upon his remark with this description of how the program was managed:

> The program was started in a marvelously informal manner. Ritland and I worked out the division of labor between the two organizations as we went along. Decisions were made jointly. There were so few people involved and their relations were so close that decisions could be and were made quickly and cleanly. We did not have the problem of having to make compromises or of endless delays awaiting agreement. After we got fully organized and the contracts had been let, we began a system of management through monthly suppliers' meetings--as we had done with the U-2. Ritland and I sat at the end of the table, and I acted as chairman. The group included two or three people from each of the suppliers. We heard reports of progress and ventilated problems--especially those involving interfaces among contractors. The program was handled in an extraordinarily cooperative manner between the Air Force and CIA. Almost all of the people involved on the Government side were more interested in getting the job done than in claiming credit or gaining control.

The schedule of the program, as it had been presented to the CORONA group at its meeting in San Mateo in late March 1958, called for a "count-down" beginning about the first of July 1958 and extending for a period of 19 weeks. It was anticipated that the equipment would be assembled, tested, and the first vehicle launched during that 19-week period, which meant that the fabrication of the individual components would have had to be completed by 1 July. By the time Bissell submitted his project proposal some three weeks later, it had become apparent that the earlier tentative scheduling was unrealistic. Bissell noted in his project proposal that it was not yet possible to establish a firm schedule of delivery dates, but that it appeared probable that the first firing could be attempted no later than June 1959.

It is pertinent to note here that there was no expectation in 1958 that CORONA would still be operating over a decade later. The CORONA program got under way initially as an interim, short-term, high-risk development to meet the intelligence community's requirements for area search photographic reconnaissance pending successful development of other, more sophisticated systems planned for WS-117L. The original CORONA proposal anticipated the acquisition of only 12 vehicles, noting that at a later date it might be desirable to consider whether the program should be extended--with or without further technological improvement.

Having settled on the desired configuration and having received Presidential approval of the program and its financing, the CORONA management team moved forward rapidly with the contractual arrangements. The team of contractors for CORONA differed from the team on the WS-117L subsystem as a consequence of selecting ITEK's earth-center stabilized approach. ITEK was brought in as one of the two major subcontractors to Lockheed (General Electric being the other). However, to soften the financial blow to Fairchild, ITEK was made responsible for the design and development of the camera subsystem with Fairchild producing the camera under subcontract to ITEK. The final contractors were selected on 25 April, and a work statement was issued to Lockheed on that date. The contractors began systems designs on 28 April and completed them and submitted them for first review on 14 May. The designs were frozen on 26 July.

Thus, by mid-1958, the program was well down the road--on the contractors' side--toward meeting the goal of a first launch no later than mid-1959. The Government side, however, was running into difficulties. The first had to do with money, the second with cover, and the two were inextricably intertwined. The $31 million cost estimate for the 12-vehicle program had assumed that the cost of the THOR boosters would be absorbed by the Air Force by diverting them from the cancelled WS-117L subsystem. That assumption proved to be incorrect. An additional $18 million had to be found to pay for the 12 THORs. Further, it had been decided that an additional four launch vehicles would be required for testing of launch, orbit, and recovery procedures and that an additional three would be required for biomedical launches in support of the CORONA cover story. ARPA could not see its way clear to making DoD funds available merely for testing or for cover support when there were other DoD space programs with pressing needs for money. Consequently, CORONA management had to go back to the President for approval of a revised estimate.

By August 1958, it had also become apparent to the project's managers that the original, but as yet unannounced, cover story conceived for the future CORONA launchings (an experimental program within the first phase of WS-117L) was becoming increasingly untenable. WS-117L had by then become the subject of fairly widespread public speculation identifying it as a military reconnaissance program. It was feared that linking CORONA to WS-117L in any way would inevitably place the reconnaissance label on CORONA, and, given the hostility of the international political climate to overflight reconnaissance, there was the risk that the policy level of government might cancel the program if it should be so identified. Some other story would have to be contrived that would dissociate CORONA from WS-117L and at the same time account for multiple launchings of stabilized vehicles in low polar orbits and with payloads being recovered from orbit.

It was decided, therefore, to separate the WS-117L photo reconnaissance program into two distinct and ostensibly unrelated series: one identified as DISCOVERER (CORONA - THOR boost) and the other as SENTRY (later known as SAMOS - ATLAS boost). A press release announcing the initiation of the DISCOVERER series was issued in mid-January 1959 identifying the initial launchings as tests of the vehicle itself and later launchings as explorations of environmental conditions in space. Biomedical specimens, including live animals, were to be carried into space and their recovery from orbit attempted.

The new CORONA cover concept, from which the press release stemmed, called for a total of five biomedical vehicles, and three of the five were committed to the schedule under launchings three, four, and seven. The first two were to carry mice and the third a primate. The two uncommitted vehicles were to be held in reserve in event of failure of the heavier primate vehicle. In further support of the cover plan, ARPA was to develop two radiometric payload packages designed specifically to study navigation of space vehicles and to obtain data useful in the development of an early warning system (the planned MIDAS infrared series). It might be noted here that only one of the three planned animal-carrying missions was actually attempted (as DISCOVERER III), and it was a failure. ARPA did develop the radiometric payload packages, and they were launched as DISCOVERERs XIX and XXI in late 1960 and early 1961. (U)

The photo reconnaissance mission of CORONA necessitated a near-polar orbit, either by launching to the north or to the south. There are few otherwise suitable areas in the continental United

States where this can be done without danger of debris from an early in-flight failure falling into populated areas. Cooke Air Force Base near California's Point Arguello met the requirement for down-range safety, because the trajectory of a southward launch from there would be over the Santa Barbara channel and the Pacific Ocean beyond. Cooke was a natural choice, because it was the site of the first Air Force operational missile training base and also housed the 672nd Strategic Missile Squadron (THOR). Two additional factors favored this as the launch area: the manufacturing facilities and skilled personnel required were in the near vicinity, and a southward launch would permit recovery in the Hawaii area by initiating the ejection/recovery sequence as the satellite passed over the Alaskan tracking facility. The name was changed from Cooke to Vandenberg AFB in October 1958.

Unlike the U-2 flights, launchings of satellites from U.S. soil simply could not be concealed from the public. Even a booster as small as the THOR (small, that is, in comparison with present-day space boosters) launches with a thunderous roar that can be heard for miles; the space vehicle transmits telemetry than can be intercepted; and the vehicle can be detected in orbit by radar skin-track. Although the fact of a launch having been made could not be concealed, maintenance of the cover story for the DISCOVERER series required that the launchings of the uniquely configured photographic payloads be closed to observation by unwitting personnel. Vandenberg was excellent as a launch site from many standpoints, but there was one feature of it that posed a severe handicap to screening the actual launches from unwanted observation: the heavily traveled Southern Pacific railroad passes through it. The boosting and station-keeping capacity of the early THOR/AGENA combination limited film supply to a one-day mission consisting of 17 orbits, seven of which would pass over denied territory. The requirements for daylight recovery and for the seven denied area passes also to be during daylight and with acceptable sun angles dictated a launch from Vandenberg in the early afternoon. Trains passing through the area broke up this afternoon launch window into a series of successive windows, some of which were of no more than a few minutes duration. Even today, the program is plagued by having to time the launches to occur during one of the intervals between passing trains. (U)

The planned recovery sequence involved a series of maneuvers, each of which had to be executed to near-perfection or recovery would fail. First, the AGENA would be pitched down through 120 degrees to position the satellite recovery vehicle (SRV) for retro-firing. Then the SRV would be separated from the AGENA and be spin-stabilized by firing the spin rockets to maintain it in the attitude given it by the AGENA. Next the retro-rocket would be fired, slowing down the SRV into a descent trajectory. Then the spin of the SRV would be slowed by firing the despin rockets.

Next would come the separation of the retro-rocket thrust cone followed by the heat shield and the parachute cover. The drogue (or deceleration) chute would then deploy, and finally the main chute would open to lower the capsule gently into the recovery area. The primary recovery technique involved flying an airplane across the top of the descending parachute, catching the chute or its shrouds in a trapeze-like hook suspended beneath the airplane, and then winching the recovery vehicle aboard. If the air catch failed, the recovery vehicle was designed to float long enough for a water recovery by helicopter launched from a surface ship.

While the vehicle was still in the construction stage, tests were conducted of the air recovery technique--with disheartening results. Of 74 drops using personnel-type chutes, only 49 were recovered. Using one type of operational drop chute, only four were recovered out of 15 dropped, and an average of 1.5 aircraft passes were required for the hook-up. Eleven drops of another type of operational chute resulted in five recoveries and an average of two aircraft passes for the snatch. Part of the difficulty lay in weak chutes and rigging and in crew inexperience; however, the most serious problem was the fast drop rate of the chutes. Parachutes that were available to support the planned weight of the recovery vehicle had a sink rate of about 33 feet per second. What was required was a sink rate approaching 20 feet per second so that the aircraft would have time to make three or four passes if necessary for hook-up. Fortunately, by the time space hardware was ready for launching, a parachute had been developed with a sink rate slow enough to offer a reasonable chance of air recovery.

The launch facilities at Vandenberg AFB were complete, and (1) the remote tracking and control facilities were ready for the first flight test of a THOR-AGENA combination in January 1959. The count-down was started for a launch on the 21st; however, the attempt aborted at launch minus 60 minutes. When power was applied to test the AGENA hydraulic system, certain events took place that were supposed to occur in flight but not while the vehicle was still sitting on the launch pad. The explosive bolts connecting the AGENA to the THOR detonated, and the ullage rockets fired. (Ullage rockets are small solid propellant rockets attached to the AGENA. These rockets are fired just prior to ignition of the AGENA engine after its separation from the THOR to insure that the liquid AGENA propellants are pushed against the bottom of the tanks so that proper flow into the pumps will occur.) The AGENA settled into the fairing attaching it to the THOR and did not fall to the ground, but appreciable damage was done.

A program review conference was held in Palo Alto two days after the launch failure to examine the possible causes of the abort and to assess its impact on the planned CORONA launch schedule. Fortunately, the problem was quickly identified and easily corrected, and it was felt that the system was ready for resumption of test launches at the rate of about one per month.

General Electric surfaced a new problem with the re-entry vehicle at the review conference having to do with the stability of the nose cone during re-entry. The cone was designed for a film load of 40 pounds, but the first missions would be able to carry only 20 pounds. GE reported that about three pounds of ballast would have to be carried in the forward end of the cone to restore stability. The program officers decided to add an instrument package as ballast, either for diagnostic purposes or for support of the biomedical cover story, thus converting what could have been dead weight into a net plus for the test program.

The test plan contemplated arriving at full operational capability at a relatively early date through sequential testing of the major components of the system--beginning with the THOR-AGENA combination alone, then adding the nose cone to test the ejection/re-entry/recovery sequence, and finally installing a camera for a full CORONA systems test. Just how much confidence the project planners had in the imminence of success cannot now be discovered; however, if the confidence factor was very high at the start, it must soon have begun to wane. Beginning in February 1959 and extending through June 1960 an even dozen launches were attempted, with eight of the vehicles carrying cameras, and all of them were failures; no film capsules were recovered from orbit. Of the eight camera-carrying vehicles, four failed to achieve orbit. Of the four vehicles that went into orbit, three experienced camera or film failures, and the fourth was not recovered because of a malfunction of the re-entry body spin rockets. These summaries of the initial launch attempts illustrate the nature and dimensions of the problems for which solutions had to be found.

DISCOVERER I

The on-pad failure of 21 January was not assigned a number in the DISCOVERER series. DISCOVERER I was launched on 28 February

HANDLE VIA BYEMAN
CONTROL SYSTEM ONLY

1959 with a light engineering payload as a test of THOR-AGENA performance. No recovery was planned. For a time there was uncertainty as to what had happened to it, because no radio signals were received. It was later established as being in orbit on the basis of radar skin-track. The speculation was that the protective nose cone over the antennas was ejected just before the AGENA fired and that the AGENA then rammed into the nose cone, damaging the antennas.

DISCOVERER II

The second vehicle was launched on 13 April 1959. Orbit was officially announced about two hours later, along with a statement that the capsule carried a light-weight biomedical payload (as indeed it did). The Air Force reported on 15 April that plans to recover the capsule near Hawaii had been abandoned and that the capsule might descend somewhere in the Arctic. The announcement slightly understated the known facts. The capsule had ejected on the 17th orbit as planned, but a timing malfunction (actually a human programming error) had caused the ejection sequence to be initiated too early. The capsule was down, probably somewhere in the near-vicinity of the Spitsbergen Islands north of Norway. In fact, there were later reports that the falling capsule had actually been seen by Spitsbergen residents. The Air Force announced on the 16th that the Norwegian government had authorized a search for the capsule, which would begin the following day. Planes scoured the area, and helicopters joined the search on the 20th. Nothing was found, however, and the search was abandoned on the 23rd. There was speculation at the time, although no evidence, that the capsule had been recovered by someone other than the American recovery team.

The incident later became the subject of a book by Alistair MacLean, Ice Station Zebra, and of a 1968 movie of the same name. The fictionalized version departed rather substantially from the facts: a U.S. nuclear-powered submarine is headed for the North Pole to rescue a team of British weather scientists marooned on an ice floe that is breaking up. On board is a team of special agents on assignment to locate and bring back a capsule containing high-resolution photographs of all missile sites in the U.S., which had been taken from a Russian satellite equipped with a new type of camera that had been stolen from the U.S. by the Russians. Meanwhile, a Russian force is also on its way to try to retrieve the capsule. It's an exciting movie, although it is plain that no one who has left the CORONA program wound up as a technical consultant to MGM.

DISCOVERER III

Much publicity attended the launching of DISCOVERER III: some of it planned and some unplanned (and unwanted). This was the first (and only) DISCOVERER flight to carry animals: four live black mice. Black mice were chosen in order to ascertain the possible hair-bleaching effects of cosmic rays. The mice were members of the C-57 strain, a particularly rugged breed. They had been "trained," along with 60 other mice, at the Air Force's Aeromedical Field Laboratory at Holloman AFB. They were seven to ten weeks old and weighed slightly over an ounce apiece. A three-day food supply was provided, which consisted of a special formula containing peanuts, oatmeal, gelatin, orange juice, and water. Each mouse was placed in a small individual cage about twice its size, and each had a minuscule radio strapped to its back to monitor the effects of the space trip on heart action, respiration, and muscular activity.

The lift-off on 3 June 1959 was uneventful, but, instead of injecting approximately horizontally, the AGENA apparently injected downward, driving the vehicle into the Pacific Ocean and killing the mice. Looking back on the mission, the attempt to orbit the mice seems to have been jinxed from the very beginning.

Just before the first try at launch, telemetry indicated a lack of mouse activity. It was thought at first that the little fellows were merely asleep; so, a technician was sent up in a cherry-picker to arouse them. He banged on the side of the vehicle and tried catcalls, but to no avail. When the capsule was opened, the mice were found to be dead. The cages had been sprayed with krylon to cover rough edges; the mice had found it tastier than their formula; and that was that.

The second try at launch several days later with a back-up mouse "crew" was also a near-abort when the capsule life cell humidity sensor suddenly indicated 100 percent relative humidity. The panic button was pushed, and trouble-shooters were sent up to check. They found that when the vehicle was in a vertical position the humidity sensor was directly beneath the cages, and it did not distinguish between plain water and urine. The wetness dried out after awhile, all was forgiven, and the vehicle was launched--unhappily into the permanent 100 percent moisture environment of the Pacific Ocean.

Also, the timing of the launch was unfortunate. The monkeys, Able and Baker, had survived a 300-mile flight in a JUPITER nose cone on 29 May in connection with another, unrelated test program. However, Able died during minor surgery on 3 June to remove an electrode that had been implanted under his skin. (This was the date of the DISCOVERER III launch.) The British Society Against Cruel Sports made a formal protest to the U.S. Ambassador, and the press raised quite a stink about the fatal mice flight--comparing it unfavorably with the Russians' successful launching of the dog, Laika, in SPUTNIK II back in November 1957 and demanding that orbit and recovery procedures be perfected before attempting future launches of mice or monkeys.

HANDLE VIA BYEMAN
CONTROL SYSTEM ONLY

DISCOVERER IV

This flight, which was launched on 25 June 1959, was the first to carry a camera and was thus the first true CORONA mission attempt. The payload did not go into orbit, because the AGENA failed to reach the required velocity. The original cover plan had called for launches three and four to carry mice, but, because of the furore raised over the death of the mice on DISCOVERER III, this one was not "miced." Certain of the official records refer to the mission as having carried mechanical mice (vibrators to simulate mouse activity), but this turns out to have been something that was talked about but never actually tried.

There was one amusing experiment on an early flight, and it may have been on DISCOVERER IV. A means was needed for concealing the payload doors from inquisitive eyes while the vehicle was on the launch pad. The scheme that was devised was to cover the doors with fairings made of sheets of paper under which were strung two lengths of piano wire with ping-pong balls attached to the forward ends of the wires. The thought was that, as the vehicle accelerated during launch, the air flow along the vehicle skin would blow the ping-pong balls to the rear, thus tearing off the paper and exposing the payload doors. The strip-away fairing was tested by attaching it to the side of a sports car and driving the car at high speed along the Bayshore Freeway late one evening. The test proved two things:

that the fairing would tear off as intended and that the Freeway patrolmen could easily overtake a vehicle traveling at 90 miles per hour. Since the test indicated a "go" situation, at two a.m. on a foggy, chilly morning--under a blaze of floodlights--a few cents worth of paper, piano wire, and ping-pong balls were affixed to a multi-million dollar space vehicle. However, perhaps because test conditions rarely perfectly simulate operational conditions, the paper did not strip away during lift off, and no one was anxious to retest the scheme by chancing another go at the Bayshore Freeway.

DISCOVERER V

DISCOVERER V was launched on 13 August 1959 and attained orbit with a camera payload. The temperature within the spacecraft was lower than planned, and the camera failed on the first orbit. The recovery capsule was ejected at the proper time but for reasons then unknown did not show up in the recovery zone. Early in 1960 an unidentified object was discovered in space in a near-polar orbit. It was finally determined to be the recovery capsule of DISCOVERER V. Instead of deboosting it into a descent trajectory, the retro-rocket had accelerated it into a higher orbit with an apogee of 1,058 miles.

DISCOVERER VI

The sixth launch was on 19 August 1959. The vehicle achieved orbit, but the camera failed on the second revolution, and the retro-rocket malfunctioned on the recovery attempt.

HANDLE VIA BYEMAN
CONTROL SYSTEM ONLY

DISCOVERER VII

The next launch was on 7 November 1959. The AGENA failed to go into orbit.

DISCOVERER VIII

The vehicle was successfully launched on 20 November 1959, but the AGENA inserted into an eccentric orbit with an apogee of 913 miles. The camera also failed again. The satellite recovery vehicle was ejected successfully, but the parachute failed to open.

* * * * *

It had become plain by the end of November 1959 that something (or, to be more precise, many things) had to be done to correct the multiple failures that were plaguing the CORONA system. Eight THOR-AGENA combinations and five cameras had been expended with nothing to show for the effort except accumulated knowledge of the system's weaknesses. The project technicians knew what was going wrong but not always why. Through DISCOVERER VIII, the system had experienced these major failures:

One misfired on the launch pad.
Three failed to achieve orbit.
Two went into highly eccentric orbits.
One capsule ejccted prematurely.
Two cameras operated briefly and then failed.
One camera failed entirely.
One experienced a retro-rocket malfunction.
One had very low spacecraft temperature.

HANDLE VIA BYEMAN
CONTROL SYSTEM ONLY

A panel of consultants reviewed the various failures and their probable causes and concluded that what was needed most was "qualification, requalification, and multiple testing of component parts" before assembling them and sending them aloft. This called for more money. Accordingly, Bissell submitted a project amendment to the DDCI on 22 January 1960 asking approval of nearly $2 million additional to cover the costs of the testing program. He apologized to General Cabell for submitting a request for funds to pay for work that was already under way: "Although such a sequence is regrettable, there has been considerable confusion in this program as to what the amount of the overruns would be and this has made it difficult to obtain approvals in an orderly fashion in advance."

As of the fall of 1959, major problems remained to be solved in achieving an acceptable orbit, in camera functioning, and in recovering the film capsule. These were the more serious of the specific failures that were occupying the attention of the technicians:

> The AGENA vehicle was designed for use with both the THOR and the ATLAS boosters. The ascent technique used by the AGENA vehicle was essentially the same in both combinations, but there were significant differences in the method of employing the booster. In the CORONA program, in order to

HANDLE VIA BYEMAN
CONTROL SYSTEM ONLY

conserve weight, the THOR booster followed a programmed trajectory using only its autopilot. Also, the THOR thrust was not cut off by command at a predetermined velocity (as in the ATLAS); instead, its fuel burned to near-exhaustion. This relatively inaccurate boosting profile, coupled with the low altitude of CORONA orbits, imposed severe orbital injection constraints. At a typical injection altitude of 120 miles, an angular error of plus or minus 1.1 degrees or a velocity deficit of as little as 100 feet per second would result in failure to complete the first orbit. This had happened repeatedly. Lasting relief from this problem lay some distance in the future: a more powerful AGENA was being developed, and the weight of instrumentation for measuring in-flight performance on the early flights would be reduced on later operational missions. The short-term remedy lay in a drastic weight-reduction program. This was carried out in part (literally, it is said) by attacking surplus metal with tin snips and files.

The system was designed to operate without pressurization (again to conserve weight), and the acetate base film being used was tearing or breaking in the high vacuum existing in space and causing the camera to jam. A solution for this problem was found in substituting polyester for acetate base film.

The equipment was built to work best at an even and predetermined temperature. To save weight, only passive thermal control was provided. The spacecraft's internal temperature had varied on the flights thus far, and it was much lower than desired on one flight. An interim solution for this problem was found in varying the thermal painting of the vehicle skin. (Interestingly, after the system finally got into full operation, it was found that the equipment worked noticeably better when the vehicle was running hotter than the supposedly optimum temperature.)

The spin-despin rockets used to stabilize the recovery vehicle during re-entry had a tendency to explode rather than merely to fire. Several had blown up in ground tests. A solution was found in substituting cold gas spin and despin rockets.

One of the most intractable problems, which was to persist for many months, was that of placing the satellite recovery vehicle (SRV) into a descent trajectory that would terminate in the recovery zone. This required ejecting the SRV from the AGENA at precisely the right time and decelerating it by retro-rocket firing to the correct velocity and at a suitable angle. There was very little margin for error in this phase: one second of error in ejection timing represented five miles displacement of the recovery point; a retro-velocity vector error of more than ten degrees would cause the capsule to miss the recovery zone completely.

One might ask why the CORONA program officers persisted in the face of such adversity. The answer lay in the overwhelming intelligence needs of the period. The initial planning of CORONA began at a time when we did not know how many BEAR and BISON aircraft the Soviets had, whether they were introducing a new and far more advanced long range bomber than the BISON, or whether they had largely skipped the build-up of a manned bomber force in favor of missiles. There had been major changes in intelligence estimates of Soviet nuclear capabilities and of the scope of the Soviet missile program on the basis of the results of the relatively small number of U-2 missions approved for the summer of 1957. However, by 1959, the great "missile gap" controversy was very much in the fore. The Soviets had tested ICBM's at ranges of 5,000 miles, proving they had the capability of building and operating them. What was not known was where they were deploying them operationally and in what numbers. The U-2 had improved our knowledge considerably, but it could not provide the answers to the critical questions, and it was increasingly becoming less an intelligence asset than a political liability.

It was judged to be only a matter of time until one was shot down--with the program coming to an end as an almost certain consequence.

* * * * *

DISCOVERER IX

A standdown was in effect from 20 November 1959 until 4 February 1960 to allow time for intensive R&D efforts to identify and eliminate the causes of failure. DISCOVERER IX was launched on 4 February and failed to achieve orbit.

DISCOVERER X

The first recovery of film from a CORONA vehicle occurred with the launching of DISCOVERER X on 19 February 1960, but in a manner such that no one boasted of it as being a "first." The THOR booster rocket began to fishtail not long after it left the launch pad and was destroyed by the range safety officer at 52 seconds after lift-off. The payload came down about a mile from Pad 5 and was located by helicopter, which put down a team to disarm the pyrotechnics and guard the payload until it could be picked up. The recovery was made by a crew that rode to the scene by Jeep.

DISCOVERER XI

DISCOVERERs VII through X carried only a quarter of a load of film (10 pounds) to permit the carrying of additional instrumentation for testing vehicle performance. DISCOVERER XI was launched on 15 April 1960 carrying a camera and 16 pounds of film. A reasonably good orbit was achieved (380 miles at apogee and 109.5 miles at perigee), and the camera operated satisfactorily. All of the film was exposed and transferred into the recovery capsule. Unfortunately, the problem of the exploding spin rockets, which had been observed in ground tests, occurred during the recovery sequence, and the payload was lost. It might be noted that this was the first mission on which the camera operated successfully throughout the mission, primarily because of the change from acetate base to polyester base film.

DISCOVERER XII

Another standdown was imposed following the failure of DISCOVERER XI. As of mid-April 1960, there had been 11 launches and one abort on pad. Seven of the launches achieved orbit, but no capsules had been recovered. DISCOVERER XII was planned as a diagnostic flight--without camera payload--heavily instrumented to determine precisely why recovery of capsules had failed previously. The vehicle was launched on 29 June 1960, but the AGENA failed to go into orbit.

DISCOVERER XIII

The next flight, on 10 August 1960, was launched as a repeat of the no-orbit DISCOVERER XII diagnostic flight, without camera and film. The vehicle was launched and successfully inserted into orbit. The

HANDLE VIA BYEMAN
CONTROL SYSTEM ONLY

recovery package was ejected on the 17th orbit, and retro-firing and descent were normal--except that the capsule came down well away from the planned impact point. The nominal impact area was approximately 250 miles south of Honolulu where C-119 and C-130 aircraft circled awaiting the capsule's descent. The splash-down occurred about 330 miles northwest of Hawaii. The airplanes were backed up by surface ships deployed in a recovery zone with a north-south axis of some 250 miles and an east-west axis extending about 550 miles to either side of the expected impact point. Although beyond the range of the airborne recovery aircraft, the DISCOVERER XIII capsule descended near enough to the staked-out zone to permit an attempt at water recovery. A ship reached the scene before the capsule sank and fished it out of the ocean. Much of the credit for the success was attributed to the inauguration (on the unsuccessful DISCOVERER XII launch) of the cold gas spin and despin rocket system.

For the first time ever, man had orbited an object in space and recovered it according to plan. This American space "first" beat the Russians by just nine days. The Soviets had tried to recover SPUTNIK IV the previous May but failed when the recovery capsule ejected into a higher orbit. They did succeed in de-orbiting and recovering SPUTNIK V carrying the dogs, Belka and Strelka, on 20 August 1960.

HANDLE VIA BYEMAN
CONTROL SYSTEM ONLY

Arrangements were made for extensive publicity concerning this success in recovering an object from orbit--in large measure to support the cover story of DISCOVERER/CORONA as being an experimental space series. News photos were released of the lift-off from Vandenberg, of the capsule floating in the ocean, and of the recovery ship, Haiti Victory. President Eisenhower displayed the capsule to the press, and it was later placed on exhibit in the Smithsonian Institution for public viewing. (There is some reason for suspecting that the capsule displayed by the President and exhibited at the Smithsonian could have been a ringer. There is an obscurely worded reference in the project files to the building of externally identical crates and to the switching of the crates. It may be conjectured--and it is only conjecture--that it was planned to substitute an unused capsule for the one that was recovered. The plan--if there was indeed one--may not actually have been carried out, and whether it was or was not is perhaps of little importance a decade after the fact.)

We have all watched television coverage of the U.S. man-in-space programs with the recovery of astronauts and capsules after splash-down in the ocean. A helicopter flies from the recovery ship to the floating capsule and drops swimmers to attach a line to the capsule. After the astronauts are removed, the helicopter hoists the capsule from the water and carries it to the recovery ship. What most of us don't realize is that the recovery technique was developed for and perfected by the CORONA program as a back-up in event of failure of the air catch.

DISCOVERER XIV

Success!!! DISCOVERER XIV was launched on 18 August 1960, one week after the successful water recovery of the DISCOVERER XIII capsule. The vehicle carried a camera and a 20-pound load of film. The camera operated satisfactorily, and the full load of film was exposed and transferred to the recovery capsule. The AGENA did not initially position itself in orbit so as to permit the recovery sequence to occur. It was on the verge of tumbling during the first few orbits, and an excessive quantity of gas had to be used in correcting the situation. Fortunately, vehicle attitude became stabilized about midway through the scheduled flight period, thus relieving the earlier fear that recovery would be impossible. The satellite recovery vehicle was ejected on the 17th pass, and the film capsule was recovered by air snatch.

The film was flown to the Eastman Kodak processing facility in Rochester, New York, for development and was then delivered to PIC (now known as NPIC) for readout and reporting. Although of substantially lower resolution than that obtainable from the U-2, the photography was of intelligence value, covered areas of the Soviet Union that had not been reached by the U-2, and this one satellite mission yielded more photographic area coverage than the total of all U-2 missions that had been flown over the Soviet Union. Aside from the expected lower resolution, the only major deficiencies in the photography were plus and minus density bars (pressure streaks) running diagonally across the format.

A press release announced the success of the mission but naturally made no mention of the real success: the delivery of photographic intelligence. The announcement noted that the satellite had been placed into an orbit with a 77.6 degree inclination, an apogee of 502 miles, a perigee of 116 miles, and an orbital period of 94.5 minutes. A retro-rocket had slowed the capsule to re-entry velocity, and a parachute had been released at 60,000 feet. The capsule, which weighed 84 pounds at recovery, was caught at 8,500 feet by a C-119 airplane on its third pass over the falling parachute.

The program officers did not take the success of DISCOVERER XIV to mean that their problems with the system were at an end, even though many of the earlier difficulties had been surmounted. The orbital injection technique had improved to a point such that vehicles were repeatedly put into orbit with injection angle errors of less than four-tenths of a degree. The timing of the initiation of the recovery sequence had been so refined that ejection of the DISCOVERER XI SRV occurred within five seconds of the planned time.

Parachute deceleration and air catch of the capsule had been accomplished repeatedly with capsules dropped from high-altitude balloons. The last two cameras placed in orbit had operated well. However, there were other critical problems that remained to be solved. Foremost among them at the time was that of consistently achieving the correct retro-velocity and angle of re-entry of the recovery vehicle. The DISCOVERER XIV capsule was the only one thus far that had descended in the designated impact zone. This was a problem that was to receive major attention during the next few weeks.

Four more cameras were launched within the next four months with one success and three failures. DISCOVERER XV was sent aloft on 13 September. The vehicle was successfully inserted into orbit, and the camera functioned properly. However, the recovery vehicle re-entered at the wrong pitch attitude, causing the capsule to come down outside the recovery zone and demonstrating that the technicians' concern over the retro-firing sequence was well founded. The capsule was located, but it sank before a recovery ship could reach it. DISCOVERER XVI was launched on 26 October, but the AGENA failed to go into orbit because of a malfunction of a timing device.

The first ten camera-equipped vehicles carried what was known as the C camera: a single, vertical-looking, reciprocating, panoramic camera that exposed the film by scanning at a right angle to the line of flight. DISCOVERER XVI carried the first of a new series of cameras known as the C Prime (C'). The C' differed only slightly from the original C configuration and was essentially little more than a follow-on procurement of the C camera.

The DISCOVERER XVII mission was launched on 12 November and went the full route through successful air catch--except for one mishap: the film broke after 1.7 feet of the leader had fed through the camera. There is an inconsistency in the available records on this and the succeeding mission. The press release concerning this mission announced that the AGENA B, a more powerful second-stage engine, was used for the first time; the project files record the first use of the B vehicle on the following mission. There is support for the accuracy of the press release in the fact that this was the first flight to carry a full 39-pound film load permitting the first of the two-day missions. The capsule was recovered on the 31st orbit.

Success again! DISCOVERER XVIII was launched on 10 December 1960 carrying 39 pounds of film. Orbit was achieved, and the camera worked well, exposing the entire film load. The recovery vehicle was ejected on revolution number 48 after three days in orbit, and the capsule was retrieved by air snatch. This was the first successful mission employing the C' camera and the AGENA B second stage. There was fogging on the first, second, and last frame of each photo pass, but image quality was otherwise as good as the best from DISCOVERER XIV.

Of the next ten launches, extending from December 1960 through 3 August 1961, only four were CORONA missions. DISCOVERERs XIX and XXI carried radiometric payloads in support of the CORONA cover story, and they were not intended to be recovered. DISCOVERER XXI included an experiment that was to be of major significance in the later development of CORONA and other space programs: the AGENA engine was successfully restarted in space.

DISCOVERER XX was the first of a dozen launches extending over a period of three years carrying mapping cameras, which the President had approved for inclusion within the CORONA project. (1) The purpose of the mapping program, which was known as ARGON, was to obtain precise geodetic fixes and an extension of existing datum planes within the Soviet Union. ARGON accomplished substantially less than its intended goal, in large part because of the limitations imposed by the very short focal length of the mapping camera.

DISCOVERER XX was itself a bust on a number of counts: the camera failed; there were no shutter firings; and the orbital programmer malfunctioned. This last-named failure led to an important change in control procedures for CORONA. On this and all prior flights the recovery sequence was initiated automatically by an ejection command cut into the program tape. The program timer failed temporarily on orbit 31 of this mission causing the entire sequence to be about one-half cycle out of phase. The automatic initiation of the recovery sequence was eliminated from the program tape on subsequent missions. Thereafter, the positive issuance of an ejection command was required.

Of the four CORONA missions attempted between December 1960 and August 1961, two did not go into orbit as a consequence of AGENA failures, and two were qualified successes. DISCOVERER XXV was launched on 16 June and exposed its full load of film. The air catch failed, but the back-up water recovery was successful. The camera failed on revolution 22 of DISCOVERER XXVI, which was launched on 7 July, but about three-quarters of the film was exposed and was recovered by air catch.

Going into August 1961, a total of 17 camera-carrying CORONA missions had been attempted, and usable photography had been recovered from four of them. An appreciation of the capacity of the CORONA camera to photograph large areas of the earth's surface can be gotten from the fact that just four successful missions had yielded plottable coverage of some 13 million square miles, representing nearly one-half of the total area of interest. Part of this coverage was redundant as a consequence of multiple photographic passes over the same target areas and would become increasingly so as long as mission life remained at two days.

The first substantial upgrading of the CORONA camera system came with the introduction in August 1961 of the C Triple Prime (C''') camera. The original C camera was a scanning panoramic camera in which the camera cycling rate and the velocity-over-height ratio were constant and were selected before launching. Image motion compensation was fixed mechanically to the velocity-over-height ratio. A brief explanation of these terms may be helpful in understanding the nature of the problems with which the camera designers had to cope.

> A means must be provided for matching the number of film exposures in a given period of time (camera cycling rate) with the varying ratio between vehicle altitude and velocity on orbit (velocity-over-height) so that the ground area is photographed in a series of swaths with neither gaps nor excessive overlapping in the coverage.
>
> If the subject moves just as a snapshot is taken with a hand-held camera, and if the camera shutter speed is not fast enough to "stop" the motion, the photographic image will be smeared. To a camera peering down from an orbiting CORONA

space vehicle, the earth's surface appears to be passing beneath the camera at a speed of roughly five miles per second. A camera photographing the earth's surface from a satellite moving at that speed would yield smeared photography if some means were not provided for stopping the relative motion. The technique used in accomplishing this is known as image motion compensation.

The C''' was also a reciprocating camera with a rotating lens cell, which exposed the film during a segment of its rotation. The new camera had a larger aperture lens, an improved film transport mechanism, and a greater flexibility in command of camera and vehicle operations--especially as regards control of the velocity-over-height factor. The larger aperture lens permitted use of slower film emulsions, which, combined with the improved resolving power of the lens itself, offered the prospect of yielding photography with a ground resolution approximately twice as good as with the C and C' cameras.

The first C''' camera system with a 39-pound film load was launched on 30 August 1961. The mission was a success, with the full film load being transferred and with ejection and recovery occurring on the 32nd revolution. However, all frames of the photography were out of focus. The cause was identified and was corrected by redesigning the scan head. Seven more missions were launched during the last four months of 1961, three with the C' camera and four with the C'''. Six of them attained orbit, and the cameras operated satisfactorily on all six. Film was recovered from four of the missions. The last of the four, which carried a C''' camera system, was rated the best mission to date. It also had a cover assignment to carry out: the injection of a secondary satellite, dubbed OSCAR, into a separate orbit. OSCAR was a small radio satellite broadcasting a signal on 145 megacycles for pick up by amateurs as an aid in the study of radio propagation phenomena.

Slowly but surely the bugs were being worked out, but it seemed that just as one was laid to rest another arose to take its place. Perhaps what was actually happening was that various sets of problems existed simultaneously, but the importance of some of them was masked by others. The elimination of a particular problem made it possible to recognize the significance of another. The recent successes had resulted largely from correcting weaknesses in the payload portion of the system. At the same time, difficulties in the AGENA vehicle began to surface. Of the last seven missions in 1961, four experienced on-orbit difficulties with the AGENA power supply or control gas system.

Power system components for general use in satellite systems were designed, developed, and tested in the CORONA program. Foremost among those components were the static electronic inverters used to convert direct current battery energy into the various alternating current voltages required by the other subsystems. Static inverters, which were first flown aboard CORONA vehicles, were considered essential, because they had half the weight and double the efficiency of their rotary counterparts. Unfortunately, they are rather temperamental gadgets. The history of inverter development had been marked by high failure rates in system checkouts on the ground. Despite the lessons that had been learned and the improvements in circuit design that resulted from them, the recent on-orbit power failures demonstrated a need for further research and development.

The AGENA failed on DISCOVERER XXXVII, launched on 13 January 1962, and the payload did not go into orbit. It was the last mission to carry the C''' camera system, and with it the DISCOVERER series came to an end. After 37 launches or launch attempts, the cover story for DISCOVERER had simply worn out. With the improved record of success and the near-certainty of an even better record in the future, it seemed likely that there would be as many as a dozen and a half to two dozen launches per year for perhaps years to come. The cover story that DISCOVERER was an experimental series had ceased to be tenable, and no other cover story was available to account for the number of launches and their unique mission profiles. So, beginning with the 38th launch, CORONA missions were announced merely as being secret Air Force satellites. On 18 April 1962, the Air Force announced the issuance of a new directive classifying all information pertaining to military satellites and eliminating the DISCOVERER, SAMOS, and MIDAS series designations. (1)

The 1961 R&D effort was not confined to improving the performance of the existing system. A major development program was concurrently under way on a much better camera subsystem. A contract was awarded on 9 August 1961, retroactively effective to 20 March, for a new camera configuration to be known as MURAL. The MURAL camera system consisted essentially of two C''' cameras mounted with one pointing slightly forward and the other slightly backward. Two 40-pound rolls of film were carried in a double-spool film supply cassette. The two film webs were fed separately to the two cameras where they were panoramically exposed during segments of the lens cells' rotations and then were fed to a double-spool take-up cassette in the satellite recovery vehicle. The system was designed for a mission duration of up to four days.

The vertical-looking C, C', and C''' cameras had photographed the target area by sweeping across it in successive overlapping swaths. The MURAL concept involved photographing each swath area twice. The forward-looking camera first photographed the swath at an angle 15 degrees from the vertical. About a half-dozen frames later, the backward-looking camera photographed the same swath at an angle also 15 degrees from the vertical. When the two resulting photographs of the same area or object were properly aligned in a stereo-microscope, the photography would appear to be three-dimensional. Simultaneous operation of both instruments was required for stereo photography. If either camera failed, photography could still be obtained from the other, but it could be viewed in only two dimensions.

The first MURAL camera system was launched as program flight number 38 on 27 February 1962. The twenty-sixth, and last in the series, was launched on 21 December 1963. Twenty of the SRV's were recovered, 19 of them by air snatch. The one water recovery was of a capsule that splashed down a thousand miles from the nominal impact point. Of the six vehicles that failed, two malfunctioned in the launch sequence, one SRV failed to eject properly, and three capsules came down in the ocean and sank before they could be recovered. Twenty successes out of 26 tries was a remarkable record when viewed against the difficulties experienced only two years earlier.

The three capsules that sank came down in or near the recovery zone, indicating that the problems previously encountered in the re-entry sequence had been solved. They were not supposed to sink so quickly, however. (One of them floated for less than three minutes.) To minimize the chance of a capsule being retrieved by persons other than the American recovery crew, the capsules were designed to float for a period ranging originally from one to three days and then to sink. The duration of the flotation period was controlled by a capsule sink valve containing compressed salt, which would dissolve in sea water at a rate that could be predicted within rather broad limits. When the salt plug had dissolved, water entered the capsule, and it sank--ingenious but simple.

Project personnel give an amusing account of the testing of the rate at which the sink valve salt plug would dissolve. They found an old four-legged tub and set it up in the test facility. The tub was filled with sea water to make sure that the tests would exactly match the conditions existing at splash down. The tub was large, and filling it required making repeated trips to Half Moon Bay with a 50-gallon drum in the back of a pick-up truck. At first, the drum was filled from an old wooden dock extending into the bay, but the owner caught them filling the drum one day and chased them off. He seemed less concerned over the use of his dock than with the wholesale pilfering of "his" sea water. Thereafter, the salt water acquisition crew had to descend to the bay on foot along a steep and twisting natural path leading down the cliff. Carrying a full drum weighing something over 400 pounds back up the path was not an easy task. The ascents were made without incident, but on one descent the barrel-carrier stumbled and pitched headlong into the bay. He is cited by project personnel as being a man who really threw himself into his work.

Other significant improvements in the CORONA program were inaugurated during the lifetime of the MURAL system. One of them was an aid to photo-interpretation. In order to read out the photography, there are certain collateral facts that the photo-interpreter must be told or be able to determine about each frame of the photography. He must be able to ascertain the portion of the earth's surface that is imaged, the scale of the photography, and its geometry. In simplest terms, he must know where the vehicle was and how it was oriented in space at the precise time the picture was taken. Until 1962, the ground area covered by a particular frame of photography was identified by combining data provided on the orbital path of the vehicle with the time of camera firing. The orientation or attitude of the vehicle on orbit was determined from horizon photographs recorded at each end of every other frame from a pair of horizon cameras that were included in the CORONA camera system.

Beginning with the first of the MURAL flights, an index camera was incorporated into the photographic system, and a stellar camera was added a few missions later. The short focal length index camera took a small scale photograph of the area being covered on a much larger scale by successive sweeps of the pan cameras. The small scale photograph, used in conjunction with orbital data, simplified the problem of matching the pan photographs with the terrain. Photographs taken of stars by the stellar camera, in combination with those taken of the horizons by the horizon cameras, provided a more precise means of determining vehicle attitude on orbit.

The photography from program flight number 47, a MURAL mission launched on 27 July 1962, was marred by heavy corona and radiation fogging. The corona problem was a persistent one--disappearing for a time only to reappear later--and had become even more severe with the advent of the complicated film transport mechanisms of the MURAL camera. Corona marking was caused by sparking of static electricity from moving parts of the system, especially from the film rollers. The problem was eventually solved by modifications of the parts themselves and by rigid qualification testing of them. [redacted]

The boosting capacity of the first-stage THOR was substantially increased in early 1963 by strapping to the THOR a cluster of small solid-propellant rockets, which were jettisoned after firing. This Thrust Augmented THOR, or TAT as it came to be known, was first used for the launching of the heavier LANYARD camera system. LANYARD was developed within the CORONA program as a modification of one of the cameras designed for the SAMOS system and, with its longer focal length, was expected to yield better resolution than the CORONA cameras. It had a single lens cell capable of stereoscopic coverage by swinging a mirror through a 30-degree angle. Three flights were attempted, only one of which was partially successful. The camera had a serious lens defect, which was later identified and corrected. The LANYARD program was initiated as an interim system pending the completion of a high-resolution spotting system then under development. It was cancelled upon the success of the spotting system. The TAT booster itself was a signal success, permitting the later launching of heavier, more versatile CORONA systems.

Program flight number 69, launched on 24 August 1963, introduced the first two-bucket configuration--the next major upgrading of the CORONA system. (The film recovery capsule is commonly referred to as a bucket, although it more nearly resembled a round-bottomed kettle.) The new modification, which was known as the J-1 system, retained the MURAL stereoscopic camera concept but added a second film capsule and recovery vehicle. With two SRV's in the system, film capacity was increased to 160 pounds (versus the 20-pound capacity of the first few CORONA missions). The two-bucket system was designed to be deactivated or stored on orbit in a passive (zombie) mode for up to 21 days. This permitted the recovery of the first bucket after half of the film supply was exposed. The second bucket could begin filling immediately thereafter, or its start could be delayed for a few days. A major redesign of the command and control mechanisms was required to accommodate the more complicated mission profile of the two-bucket system.

As with each of the major modifications of CORONA, the J-1 program had a few early bugs. On the first mission, the shutter on the master horizon camera remained open about 1,000 times seriously fogging the adjacent pan photography, and the AGENA current inverter failed in mid-flight making it impossible to recover the second bucket. Also, the J-1 system initially experienced a rather severe heat problem, which was solved by reducing the thermal sensitivity of the camera and by better control of vehicle skin temperature through shielding and varying the paint pattern.

Back in 1960 and 1961, the successful recovery of a CORONA film bucket was an "event." A mere two years later with the advent of the J-1 system, success had become routine, and a failure was an "event." By the end of 1966, 37 J-1 systems had been launched; 35 of them were put into orbit; and 64 buckets of film were recovered. There were no failures at recovery in the three years following 1966: 28 buckets were launched, and 28 buckets were recovered. Also, mission duration was greatly expanded during the lifetime of the J-1 system. A mission in June 1964 yielded four full days over target on each of the two buckets. Five full days of operation on each bucket was attained in January 1965. In April 1966, the first bucket was recovered after seven days on orbit. A 13-day mission life was achieved in August 1966, and this was increased to 15 days in June 1967.

The increased mission life and excellent record of recovery resulted from a number of successive improvements that were incorporated into the J-1 program. Among them was a subsystem known as LIFEBOAT, a completely redundant and self-contained apparatus built into the AGENA that could be activated for recovering the SRV in event of an AGENA power failure (which still happened occasionally). Another improvements was the introduction of the new and more powerful THORAD booster. A third was the addition of a rocket orbit-adjust system. The CORONA vehicles were necessarily flown with a quite low perigee over the target areas in order to increase the scale of the photography; however, the low perigee resulted in a relatively rapid decay of the orbit. The orbit-adjust system compensated for the decay. It consisted of a cluster of small rockets, known as drag make-up units, which were fired individually and at selected intervals. Each firing accelerated the vehicle slightly, boosting it back into approximately its original orbital altitude.

The CORONA camera system was to undergo one more major upgrading, converting it into the system that is in operation today, but we cannot leave the J-1 program without giving an account of one mission failure of truly magnificent proportions. Program flight number 78 (CORONA Mission Number 1005), a two-bucket J-1 system, was launched on 27 April 1964. Launch and insertion into orbit were uneventful. The master panoramic camera operated satisfactorily through the first bucket, but the slave panoramic camera failed after 350 cycles when the film broke. Then the AGENA power supply failed. Vandenberg transmitted a normal recovery enable command on southbound revolution number 47 on 30 April. The vehicle verified receipt of the command, but nothing happened. The recovery command was repeated from various control stations--in both the normal and back-up LIFEBOAT recovery modes--on 26 subsequent passes extending through 20 May. The space vehicle repeatedly verified that it had received the commands, but the ejection sequence did not occur. No further recovery commanding was attempted after the 20th, since the vehicle had ceased on the 19th to acknowledge receipt. The Mission 1005 space hardware was doomed to incineration. The vehicle would gradually sink into a progressively lower orbit until it finally entered the atmosphere and was destroyed in a fiery display of exploding rockets and gas bottles and of blazing vehicle fragments.

It didn't happen quite that way, however. A commercial photographer named [redacted] telephoned the American Embassy in Caracas on 1 August 1964 to report that he had photographed a space satellite that had fallen in Venezuela. The report set in train a series of enquiries that discovered, after the fact, what had happened to Mission 1005.

At six minutes past midnight on the morning of 26 May, coinciding with northbound revolution number 452 of Mission 1005, observers in Maracaibo, Venezuela, saw five incendiary objects in the sky. Seven minutes later, the Moorestown, New Jersey, SPADATS station made radar sightings of small residual objects in the atmosphere. The DEW line made three radar hits on objects of unknown size. The Thule tracking station did not detect the Mission 1005 vehicle on pass number 452.

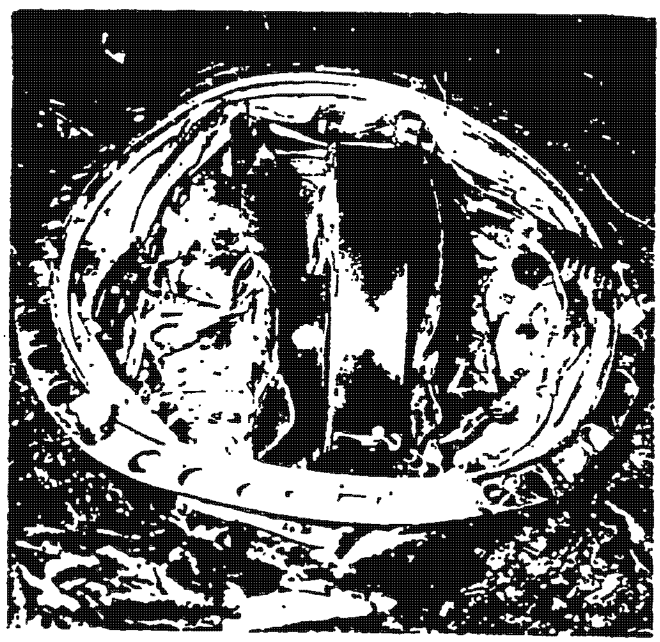
On 7 July, 14-year-old [redacted] and 40-year-old [redacted] stumbled upon a battered, glimmering gold object lying on nearly deserted mountainous terrain within a couple of miles of the Colombian border and near the village of La Fria in Tachira State in southwestern Venezuela. The object was on Farm No. 35 owned by [redacted] but [redacted] worked for [redacted] the owner of neighboring Farm No. 36. They reported their find to their employer. He had the object moved about 100 yards onto his own property and then sent out word of the find an attempt to sell the object. However, the market for fallen space objects (even gold-plated ones) is limited in Tachira, and [redacted] could not even get a worthwhile offer to have it smuggled into nearby Colombia. The find was not a total loss, however: by hacking and prying, [redacted] and his employees managed to remove the radio transmitter and various pieces of the take-up assembly, using them as household utensils and as toys for the children.

Before long, word of the find reached San Cristobal, the nearest city of any size, and people began visiting La Fria to examine the curious object from space. (It was the first bucket from Mission 1005 with one full spool of well charred film clearly visible.) One of the visitors was the photographer, [redacted] who passed the word to the American Embassy. A team of CORONA program officers, ostensibly representing the U.S. Air Force, flew to Caracas to direct the recovery

HANDLE VIA BYEMAN
CONTROL SYSTEM ONLY

[redacted]

SRV being carried out of La Fría on foot by Campesinos



On location in La Fría, Táchira

Sold to the U. S. Air Force

operation and ship the capsule and any other fragments that could be found to the States for detailed examination. The capsule was carried out part way by campesinos on foot and then was taken over by the Venezuelan Defense Ministry and flown to Caracas. The USAF bought the crumpled specimen from the Venezuelan government and quietly dismissed the event as an unimportant NASA space experiment that had gone astray.

The story rated only a dozen lines in the New York Times of August fifth, but the local Venezuelan press had a field day. Diario Catolico, of San Cristobal, along with a lengthy report, published three pictures of the capsule showing the charred roll of film on the take-up spool. The photographs are reproduced on the following page. The Daily Journal handled the story in lighter vein with this parody of Longfellow:

> I shot an arrow into the air.
> It fell to earth I know not where.
> Cape Kennedy signalled: "Where is it at you are?"
> Responded the rocket: "La Fria, Tachira."

Many of the bits and pieces that appeared in the first on-the-scene photographs, as well as other items that were known to be in the capsule, were kept by those who had handled it; however, three objects were recovered that were not supposed to have been in the capsule at all: three U.S. coins--two quarters and a buffalo nickel. They apparently had been placed in the capsule by program personnel for later recovery as souvenirs from a space flight. The Washington program office sent a sharply worded message to the west coast office charging it with responsibility for ensuring that the practice of souvenir-launching be stopped.

The CORONA technicians who examined the capsule after its arrival in the States concluded that the re-entry of the SRV came as a result of normal orbit degeneration with separation from the instrument fairing being caused by re-entry forces. The thrust cone was sheared during separation but was retained by its harness long enough to act as a drogue chute, thus preventing the capsule from burning up during re-entry and stabilizing it for a hard, nose-down landing.

The final major modification of the CORONA system got under way in the spring of 1965 at a time when about a dozen and a half of the two-bucket J-1 systems had been flown. The J-1 was performing superbly, but it had little potential for within-system growth. The new CORONA improvement program was begun with a series of meetings among representatives of Lockheed, General Electric, ITEK, and the various CORONA program offices to examine ways of bettering the performance of the panoramic and stellar/index cameras and of providing a more versatile command system. These were the resulting design goals established for a new panoramic camera:

Removal of camera system oscillating members and reduction of vibration from other moving components.

Improvement of the velocity-over-height match.

Proper camera cycling rates at altitudes down to 80 n.m. (the minimum J-1 operating altitude was 100 n.m.).

Elimination of camera failures caused by film pulling out of the guide rails (an occasional problem with the J-1 system).

Exposure control through variable slit selection.

Capability of handling alternate film types and split film loads.

Capability of handling ultra-thin base film (yielding a 50% increase in coverage with no increase in weight).

The panoramic camera that was developed to meet those design goals was known as the constant rotator. The predecessor C''' camera employed a combination of rotating lens cell and reciprocating camera members. In the constant rotator, the lens cell and the balance of the camera's optical system is mounted in a drum, and the entire drum assembly is continuously rotated, thus eliminating the reciprocating elements from the camera system. The film is exposed during a 70-degree angular segment of the drum's circular sweep. The capability of using ultra-thin base film was one of the design goals, but the camera was not actually built to accommodate the thinner film. Attempts to use it in the constant rotator were eventually abandoned. In all other respects, however, the constant rotator has been a resounding success. It has yielded substantially better ground resolution in the photography, and it permits versatility in operation far exceeding that available in reciprocating cameras.

The stellar/index camera in use was a complex and delicate instrument with a long history of erratic performance. The efforts at upgrading the performance of the stellar/index camera resulted in an instrument with a dual-looking stellar element with the jaw-breaking designation of Dual Improved Stellar Index Camera, commonly referred to by its acronym: DISIC.

The new camera system, which was designated the J-3, consisted of a pair of constant rotators, a pair of horizon cameras, and a DISIC. The J-3 system naturally retained the stereo capability begun with the MURAL cameras and the two-bucket recovery concept of the J-1. Apart from the improved picture-taking capability of the hardware itself, the most significant advance represented by the J-3 was in the flexibility it allowed in command and control of camera operations. Any conventional area search photographic reconnaissance system is film-limited. (When the film runs out, the mission is finished--assuming, of course, that other mission-limiting components of the system survive that long.) Consequently, the ultimate goal of all of the CORONA improvement efforts was to pack the maximum of the best possible quality of photography of important intelligence targets into each roll of exposed film. The built-in flexibility of the J-3 system greatly increased the variety and degree of controls that could be applied to camera operations, thus substantially boosting the potential intelligence content of the photography.

The first J-3 system was launched on 15 September 1967, and it is the system that is still in operation today--yielding even better photographic intelligence than the remarkably successful predecessor J-1 system. However, the years of CORONA as the intelligence community's only area search photographic reconnaissance satellite are about to end with the advent of a wholly new system designed to do the job even better. (1)

Looking back on CORONA as it is about to fade from the scene, it is not always easy to keep in mind that it was merely an assemblage of inanimate objects designed and put together to perform a mechanical task. The program began as a short-term interim system, suffered through adversity in its formative years, and then survived in glory for the better part of a decade. Those who were associated with the program or came to depend upon its product developed an affection for the beast that bordered on the personel. They suffered with it in failure and revelled in its successes.

The totality of CORONA's contributions to U.S. intelligence holdings on denied areas and to the U.S. space program in general is virtually unmeasurable. Its progress was marked by a series of notable firsts: the first to recover objects from orbit, the first to deliver intelligence information from a satellite, the first to produce stereoscopic satellite photography, the first to employ multiple re-entry vehicles, and the first satellite reconnaissance program to pass the 100-mission mark. By March 1964, CORONA had photographed 23 of the 25 Soviet ICBM complexes then in existence; three months later it had photographed all of them. The value of CORONA to the U.S. intelligence effort is given dimension by this statement in a 1968 intelligence report: "No new ICBM complexes have been established in the USSR during the past year." So unequivocal a statement could be made only because of the confidence held by the analysts that, if they were there to be found, CORONA photography would have disclosed them.

When the final CORONA mission is flown, history will record that the program explored and conquered the technological unknowns of space reconnaissance, lifted the curtain of secrecy that screened developments within the Soviet Union and Communist China, and opened the way for the even more sophisticated follow-on satellite reconnaissance systems.