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~~(S)~~ **QUILL**
~~(S)~~ *The First Imaging Radar Satellite*

Robert L. Butterworth

December 2002, revised December 2004

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(U) Introduction

~~(S//TK)~~ In December 1964, the NRO launched a satellite called "Quill" that successfully demonstrated electronic imaging of the Earth using a synthetic aperture radar in outer space. How this test demonstration came about, its novel results, and what became of the work are ably described in the pages that follow. Dr. Robert Butterworth has incorporated the findings of extensive documentary research with interviews and oral histories. The result is a highly readable account of how SAR revolutionary technology first came to operate in space.

(U) *Robert L. Butterworth* has been writing classified histories for the NRO for the past five years. In addition to his forthcoming history [REDACTED] [REDACTED]—he has just completed a comprehensive history of the NRO Signals Intelligence (SIGINT) programs. He is the author of several contributions to basic and applied research in national security affairs, is a former college professor, and has held staff positions in the Defense Department, the U.S. Senate, and the White House. His graduate degrees are from the University of California at Berkeley.

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(U) Preface

~~(S//FK)~~ Quill was the world's first imaging radar satellite, launched by the National Reconnaissance Office (NRO) as an experiment in 1964. The NRO was young then—only a year old, in fact, when Quill's development got under way. But several dominant traits were already apparent: dedication to developing very advanced technology, aversion to bureaucratic management, and irresolution in the face of competing military and national intelligence needs.

~~(S//FK)~~ I found pieces of this story [REDACTED] for the NRO's former History Office and the IMINT directorate—a project that was aided by scores of people and dozens of organizations. Particularly important information about Quill came from interviews with its Air Force program manager, Maj. Gen. David D. Bradburn USAF (Ret); the program manager who built the radar system at Goodyear Aerospace Corporation, Mr. [REDACTED] and the expert in Doppler data processing from the [REDACTED]

(U) I could not have completed this work without the superb research assistance of [REDACTED] and the incomparable administrative support of [REDACTED]. [REDACTED] kindly reviewed the manuscript in draft. [REDACTED] created the design and patiently copyedited several versions of the manuscript.

(U) This work began under the direction of R. Cargill Hall, NRO Historian during 1998-2003. Hall proved a rare, steady helmsman in the temperament-tossed seas of research and writing. With this monograph he very nearly had a piece of NRO program history coming out of work commissioned and published on his watch. We were too slow for that, and must settle instead for being printed as part of his significant legacy.

Robert L. Butterworth
Chantilly, Virginia
December 2004

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~~(S)~~ Radar Eyes

~~(S)~~ Military satellite work in the U.S. sputtered through the 1950s until the Soviet Union launched Sputnik in October 1957. Soon thereafter, articles in the trade press talked about an Air Force contract with Lockheed for "WS-117L," Earth reconnaissance satellites (some called "Pied Piper") that "would carry television, photographic cameras, [and] infra-red spotter or radar scanner systems."¹ A later article made further reference to payloads: "probably no single Pied Piper reconnaissance vehicle will incorporate more than one type of sensor for mapping—optical, infrared, or radar—because of payload restrictions and complexity of multiple scanning systems."² A 1958 advertisement (*Figure 1*) predicted that these satellites would "see" in various ways and that some would have "radar eyes."³

~~(S)~~ Those eyes would see using a focused synthetic aperture radar (SAR), which hit public attention on 20 April 1960, when the U.S. Army unveiled pictures of American cities taken at night and through clouds (*Figure 2*) with its new SAR system mounted in a small airplane.⁴ This new technology made it feasible that radar could be used for reconnaissance from satellites, because unlike real-aperture side-looking airborne radar (SLAR), smaller antennas actually improved resolution, and distance from the target was effectively irrelevant.⁵ At the same time, satellites appealed to SAR engineers as excellent platforms for their sensor.⁶ Unlike aircraft—whose bumps, slides, and twists through the air had to be measured and subtracted from the Doppler returns—satellites offered almost perfect stability.

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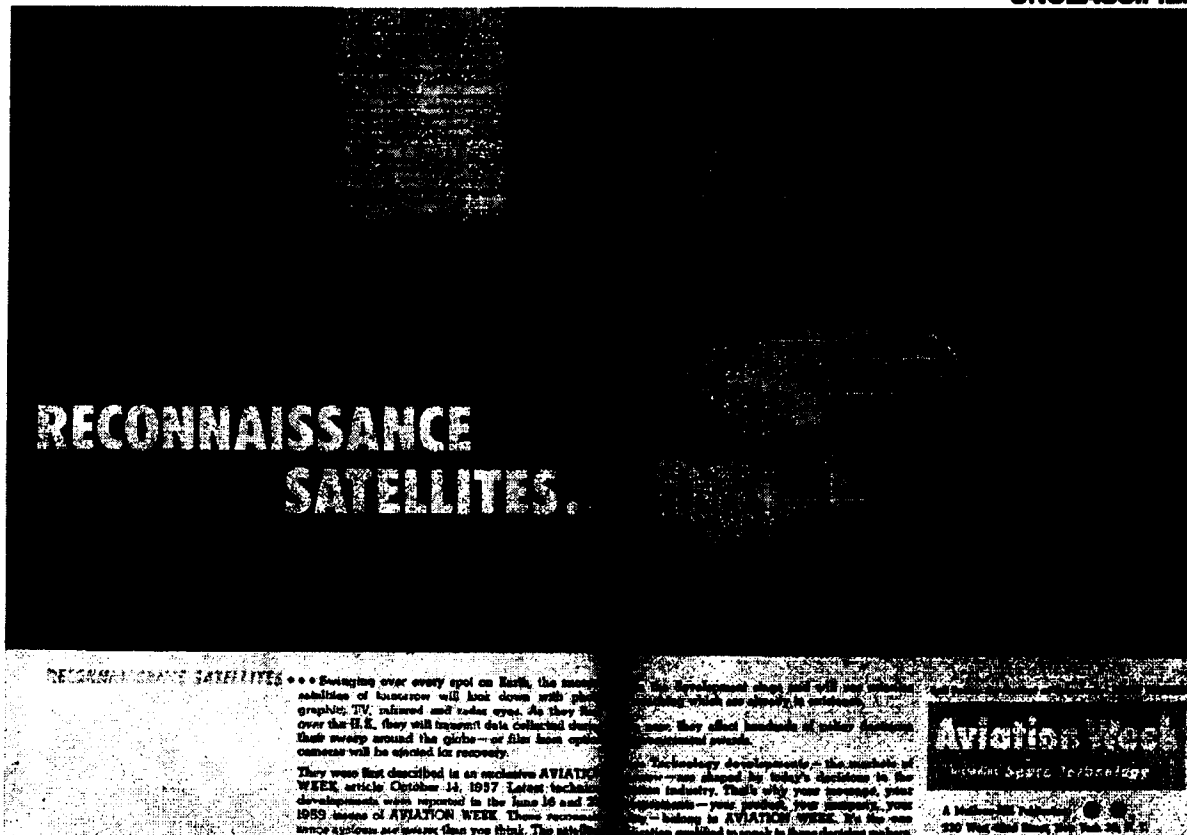


Figure 1. (U) Aviation Week advertisement, 8 September 1958, pp. 100-101

The Washington Post

Times Herald

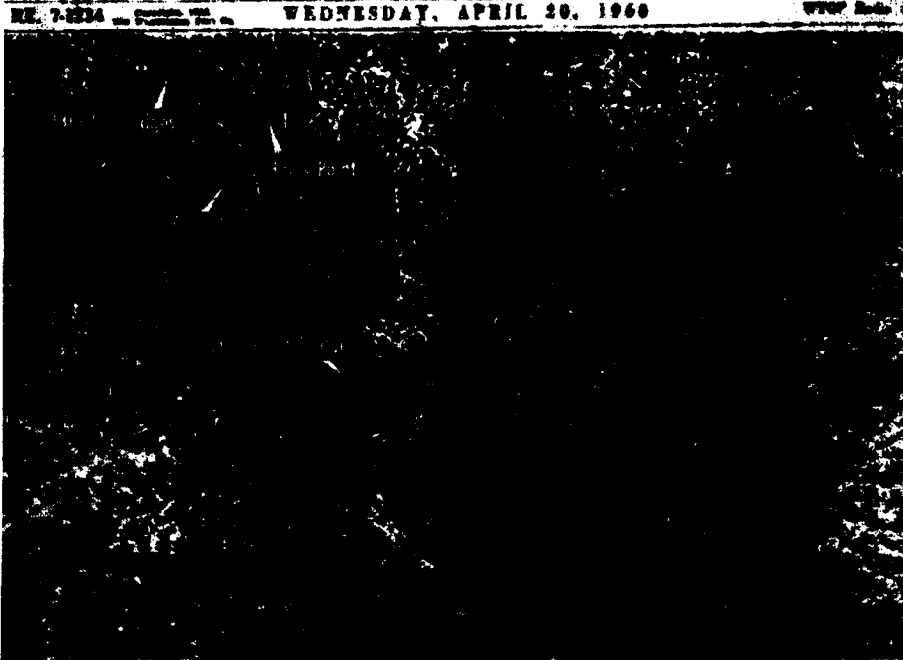


Figure 2. (S//NF) The Washington Post on 20 April 1960 displayed an early SAR image on its front page

(S//FK) By the late 1950s, several research teams were studying the prospects for SAR imaging from very high or orbital altitudes. In 1959-60 the Air Force DynaSoar program funded two research teams to study how SAR might be used from a high-altitude stable platform; one team included [REDACTED] from the Litchfield, Arizona facility of the Goodyear Aerospace Corporation, working together with engineers from the Glenn L. Martin company of Baltimore, Maryland.⁷

[REDACTED] continued its long-standing interest in radar technology with contracts in 1960 for the "Higasser" program, a classified effort to determine whether SAR images could be generated from very high orbits. Goodyear won a Higasser contract, with [REDACTED] as project engineer; the [REDACTED]

[REDACTED], a research group of the [REDACTED], did not win on Higasser, but a year later won a \$1 million study in the "Logasser" program, which looked at SAR imaging at ranges of ten to 300 miles. This proposal, and the research at [REDACTED], was led by [REDACTED], [REDACTED] employee. The research team included the Lockheed Missiles and Space Company of the Lockheed Aircraft Corporation, Sunnyvale, California, as the antenna subcontractor. Altogether they began to work on defining and resolving the technical issues in obtaining fine SAR resolution at the Earth's surface.

(S//FK) A summer exchange program in 1961 took [REDACTED] to Sunnyvale to work with Lockheed on the early Samos satellite programs. While there, he gave some lectures on radar, was hired as a consultant to Lockheed, and became in-

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volved in exploring a business development idea for using Lockheed's launcher and satellite technology and [redacted] radar imaging technology to build a SAR satellite. To build the radar itself, he recommended Goodyear as the best company.



(U//FOUO) Brig. Gen. William G. King, USAF



(U//FOUO) Maj. Gen. David D. Bradburn, USAF

Bradburn. A West Point graduate in electrical engineering, Bradburn had joined the Air Force and spent most of the 1950s serving in the Air Research and Development Command, where he became aware of the ongoing work on side-looking and synthetic aperture

He had built an optical correlator used by one of Goodyear's earlier SAR products, the APS/AP-73,⁸ and had come to know the Litchfield Park engineers, who were even then working on design parameters for a space-based SAR, such as the relationships among pulse repetition frequency, antenna length, power requirements, and coverage. [redacted] became Goodyear's project engineer for the effort, and in the summer of 1961 he and another engineer visited Sunnyvale, learned about the project, and began planning how to build the radar.

radar systems.¹⁰ He entered the satellite world in 1957, when he transferred to Los Angeles to work on the WS-117L program, and in 1961 he was serving in Program A's SP-3 office, developing security plans and procedures.



(S//FK) To assess the merits of a SAR satellite demonstration, Bradburn looked into the potential utility of a fully operational SAR satellite. After talking with officers of the Strategic Air Command (SAC), he concluded that a radar with about 10-foot resolution would be useful for post-strike bomb damage assessment, particularly because it could respond

(S//FK) At that time Col. William G. King was deputy director of the new Special Projects (SP) staff in Los Angeles, which shortly would be constituted as Program A in the newly established National Reconnaissance Office (NRO). Program A worked closely with Lockheed on both satellites and launchers, and King headed a study group looking for new ways to use satellites for national reconnaissance. Sometime in the late fall of 1961, [redacted] remembered, King's study group took up the possibility of launching a proof-of-concept synthetic aperture radar satellite.⁹ One of the group's members was Major David D.

quickly and not have to wait for clear skies and sunshine. Meanwhile, in January 1962 Goodyear began preliminary SAR design work under a contract with Program A. After several months this project had matured enough for King to propose the experiment to NRO Director Joseph V. Charyk, who approved it in mid-November 1962.¹¹ Bradburn, chosen to direct the effort,¹² summoned Goodyear's [redacted] Lockheed's [redacted] (the satellite bus expert) and [redacted] (the antenna expert), [redacted] and a few others to a meeting in Los Angeles before Thanksgiving, without telling them

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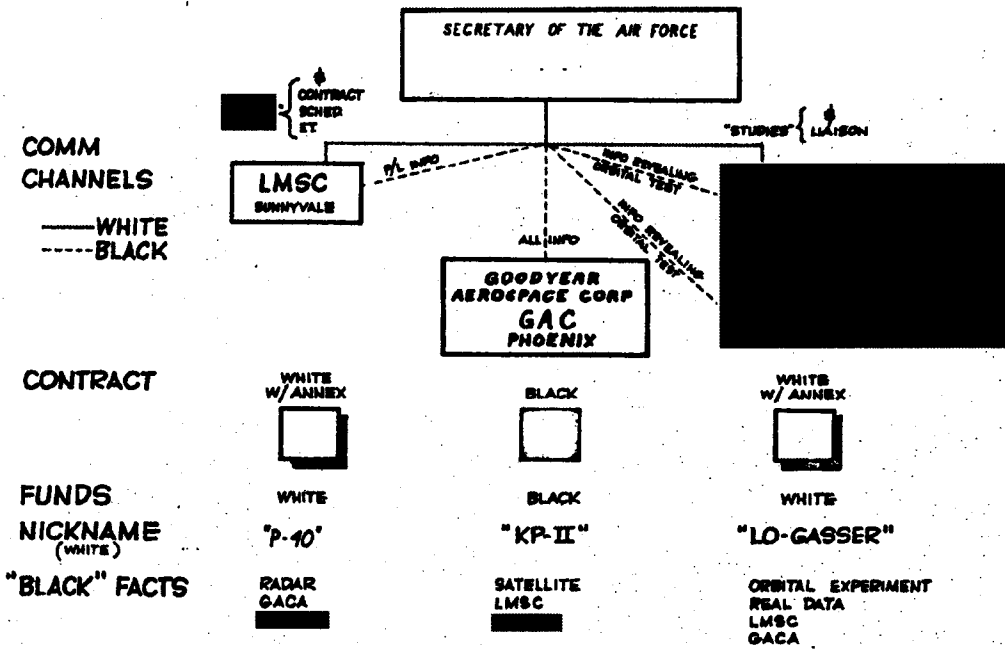


Figure 3. (S//BYE) Quill project organization
Source: Lockheed, System Report 1, p. 14

the subject. It turned out to be the official start for the SAR satellite demonstration, now known by the classified name "P-40." The satellite itself received the codeword name "Quill."

(U) Designing the Experiment

(S//FK) Proposals from industry were solicited and received in short order, and contracts structuring a tripartite industrial team (Figure 3) were awarded in November 1962.* Lockheed's group at the Agena facilities in Sunnyvale was responsible for overall systems engineering and technical direction, together with the upper stage/satellite body and associated subsystems.¹³ [redacted] was responsible for design and evaluation

of the experiment and for the optical correlator that would process radar data and produce images. Goodyear was responsible for the radar payload and for working with [redacted] in the design, test, and operation of the experiment. The contract called for launching two identical vehicles, designated 2355 and 2356, the first to go in April 1964. The payload for a third vehicle was to be prepared as well, but a booster was not identified for it.

(S//FK) Bradburn designed Quill as an experiment tightly focused on the question of orbital functionality. As Lockheed emphasized, "the primary objective of the orbital flight was to demonstrate that a fine-resolution radar strip



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map of a portion of the earth's surface can be generated through use of a satellite-borne synthetic aperture radar system. For the purpose of this demonstration a resolution goal of 50 feet in azimuth and in slant range was established."¹⁴ Secondary mission objectives included quantitative evaluations of the radar system performance (especially azimuth-direction behavior); determination of the limits imposed by payload design parameters, payload in-flight performance, vehicle attitude behavior, atmospheric conditions, and data link design and performance; and data collection on target field reflectivity, engineering parameters for aerospace radar system designs, and the capability of the ground recording equipment.

(S//FK) Quill would not seek to develop new technology or become the basis for an operational program.¹⁵ In Bradburn's view, the orbital experiment intended to answer only two questions: whether the system could really integrate Doppler-shifted radar returns over a sufficiently long path in orbit to obtain the desired azimuthal resolution, and whether there was anything about the behavior of the atmosphere that might create noise in the system. He was determined to keep the experiment focused, so he sought to minimize technology development and to use proven equipment and procedures wherever possible.¹⁶ Even so, significant errors could be introduced in several ways. There could be jitter in the transmitter's oscillator, for example, or erratic vehicle motion and errors in pitch, roll, or yaw as well as problems arising from incorrect beamwidth, atmospheric turbulence,



receiver noise, and mechanical and chemical shortcomings in the data recording system.¹⁷

(S//BYE) The radar itself, designated KP-II,* was an AN/UPQ-102 pulsed-Doppler system that Goodyear was then producing for RF-4C aircraft.¹⁸ The contract with Program A called for producing five KP-II radars, enough to provide replacements in case of launch or test failures, because the ways in which the space environment might affect the SAR were still unknown. For example, what was the barometric pressure inside the Agena launch vehicle— 10^{-3} millimeters of mercury, or 10^{-5} , or 10^{-1} because of out-gassing? The differences could be significant to the operation of power-generating devices.

(S//FK) The radar was stripped of unnecessary aerial subsystems (such as lateral motion compensation devices) and subjected to extensive reliability engineering, including testing and potting to control electrical discharge,[†] refinishing for environmental considerations, and x-ray examination of components. All the component boxes were instrumented with pressure sensors and mounted on special rubberized shock isolation mounts. Special wire was used with an insulating covering that promised little out-gassing, about which little was known in general. In keeping with the primary objective of the experiment—obtaining a terrain image from a SAR satellite—the overall system was simplified considerably and did not include capabilities that would be needed for operational systems. For example, there was no ability to select the terrain swath being imaged or to extend the length of the swath.¹⁹

* (S//FK) Goodyear designated its classified projects using the initial of the surname of its current president, who then was Tom Knowles. The orbital radar project thus became the "KP-II."

† (S//FK) [redacted] and others at Goodyear had to experiment with potting techniques as a way to keep the transmitter operating in the unknown space environment. Essentially, the electrical component was placed in a cocoon of elastic rubber inside a metal container. A vacuum was created in an effort to let the rubber set without air pockets. All leads were grounded and had wire shielding.

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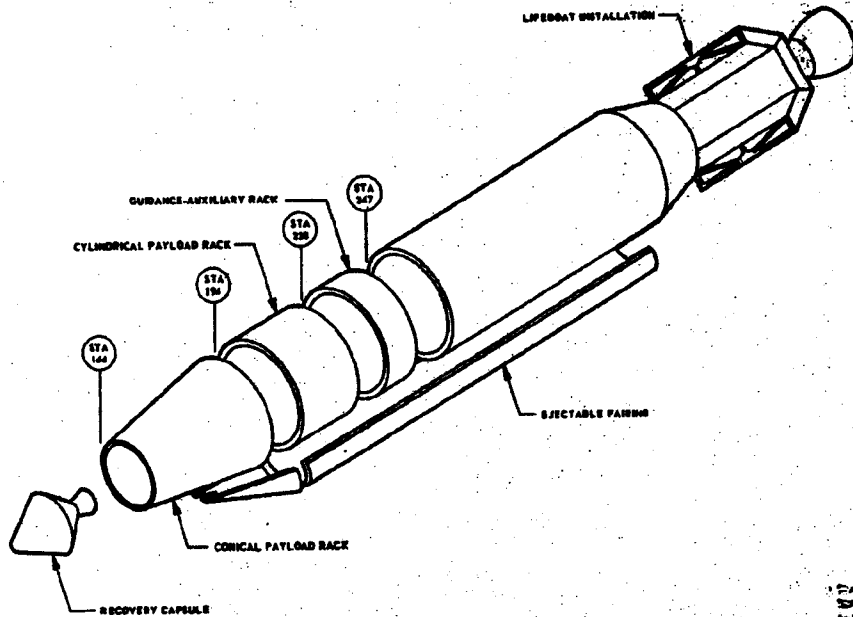


Figure 4. (S//FK) Agena D for Quill
Source: Lockheed, System Report 2, p. 1-3

(S//FK) As a Doppler system, the radar had to transmit pulses often enough to reduce azimuthal ambiguities while allowing a proper interval between pulses to record the returned signals. The timing of the pause depended on range to the target, and this distance could not be known precisely. The Goodyear engineers knew that the antenna was to look down at a 55-degree angle, but they could not know the exact altitude of the satellite. Their solution, credited to [REDACTED] was a specially designed circuit that continually monitored the pulse repetition frequency and adjusted it slightly. Had it been important for the mission, other solutions to the range issue surely could have been applied; but Bradburn said he really did not care about range resolution for Quill because it could be readily changed by shortening the pulses or other tinkering. "With Quill we just wanted enough energy on the target, we didn't care how long

high peak power needed to operate the radar.* Most of the klystrons that Goodyear used for aircraft radars were air-cooled; for Quill, the engineers designed a heat sink. It was an aluminum plate about ten inches long and five inches high and painted with a special thermally conductive white paint. Several copper fingers were braised to its back. The plate bolted to the anode of the klystron, and heat was conducted through the copper fingers to another metal heat sink, which was placed next to the satellite skin so the heat could then be radiated into space.

(S//FK) The mission was intended to last only 96 hours, with the radar operating no longer than five minutes per orbit, for no more than three orbits in succession, and for no more than 80 minutes altogether. Power was provided by three silver-zinc batteries, which determined the duration of the experiment; there was no provision for recharging them.

the pulse was, range resolution was not a parameter we cared about, we just cared about being able to do the processing trick to produce synthetic aperture with [useful azimuthal resolution]."²⁰ Base frequencies for the system would be 9600 MHz for the transmitter carrier with a pulse repetition frequency of 8215 to 8735 Hz and an intermediate frequency of 70 MHz.

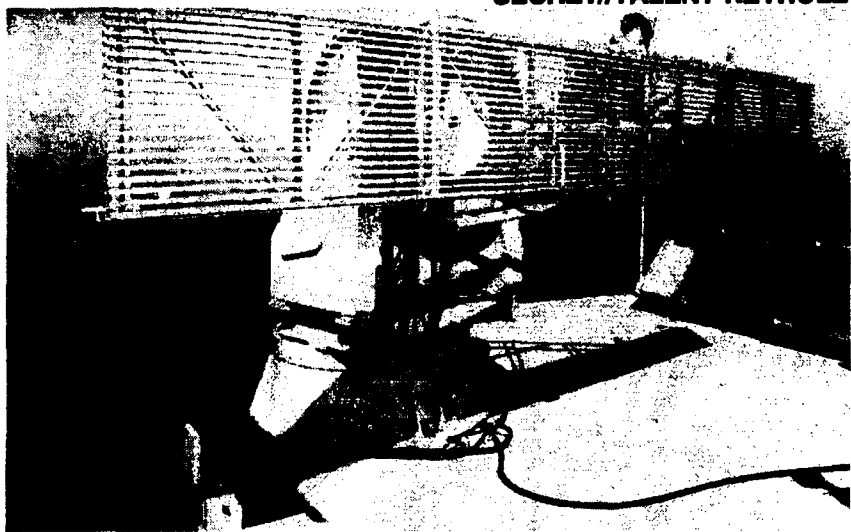
(S//FK) Another engineering challenge was thermal control, particularly for the klystron, the device that generated the

* (S) "Klystrons are a family of microwave vacuum tubes that depend upon the conversion of a velocity-modulated beam into a varying current by the process of electron bunching." A. E. Harrison, *Klystron Tubes* (New York: McGraw-Hill, 1947), p. 1.

(S//TK) The KP-II would be installed in the same Agena upper stage used as a satellite body for Corona (Figure 4). The Agena would be launched with an augmented Thor missile, constituting a flight-proven package of booster and upper stage that offered tolerable launch environments (thermal, sinusoidal vibration, random vibration, shock, acceleration, and pressure). The Agena also was expected to provide sufficient

stability for the SAR on orbit (± 0.4 degrees of attitude uncertainty and $\pm .25$ degrees limit cycle in pitch, yaw, and roll, with rates of change not greater than .002 degrees/second in pitch, .005 degrees/second in yaw, and .003 in roll).

(S//TK) The radar would transmit and receive through an antenna that was flush-mounted on the Agena body, thereby avoiding the risks associated with a design that would require un-



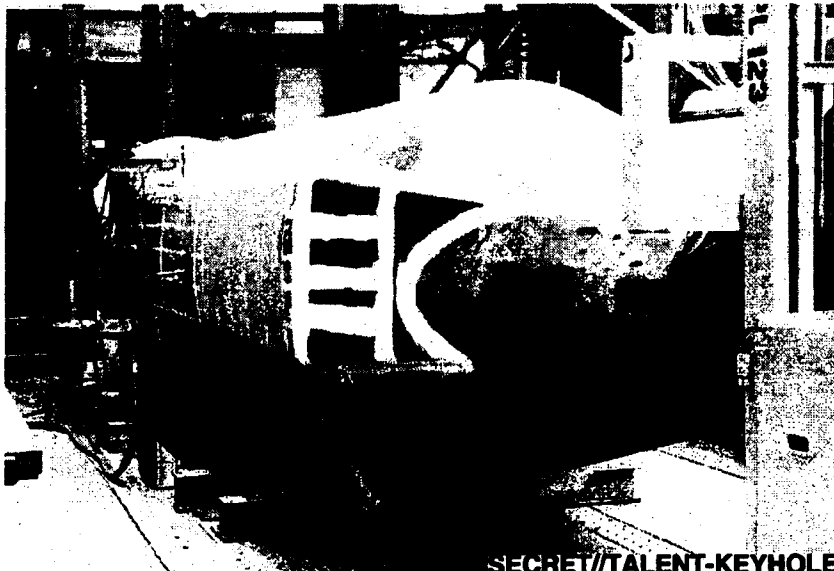
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Figure 5. (S//TK) Quill antenna
Source: Lockheed, System Report 2, p. 1-143

folding or unfurling a structure on orbit. Based on calculations that determined dimensions for maximizing the portion of the slant range interval that could be mapped, consistent with the Agena vehicle dimensions, the antenna was made 15 feet long and two feet high (Figure 5). It was manufactured by Lockheed; the company's Antenna Laboratory had considerable experience with problems posed by constructing this type of

antenna using the available stock, and its machining was done in the Agena D facility.²¹ The antenna was mounted along the right side of the Agena body, occupying nearly its entire length and, when covered by protective fairing, protruding about two and a half inches from the surface (Figure 6).

(S//TK) The fairing was designed to detach after the Thor booster engine cut off, thereby reducing the load to be lifted by the Agena motor (Figure 7). To protect the antenna from deformations



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Figure 6. (S//TK) Antenna fairing
Source: Lockheed, System Report 2, p. 1-44

that might result from thermal loads on the orbiting Agena body, three of its four mountings allowed the antenna to slide along fixed points, while the fourth was fixed to the vehicle.²²

(S//FK) After being injected into orbit, the Agena would rotate 180 degrees, so that it would fly tail first (facilitating film recovery and terrestrial coverage); the antenna would thus be located with the main lobe of the radar looking down at 55 degrees from the horizontal at a strip that would be 93 miles to the left of the satellite's ground track and 10 nautical miles wide (Figure 8).*

(S//FK) Figure 8 also displays the two directions in which the fineness of the radar's measurements was assessed: along-track (in the direction of flight) and across-track (or azimuthal, normal to the direction of flight). The figure also displays the two surfaces on which resolution is commonly measured: the slant plane (the deeply shadowed side of the prism on the ground, 5.95 nm wide for Quill), and the ground plane, labeled "imaged swath (map plane)," 10.1 nm wide for Quill.

(S//FK) The reflections from each radar pulse traced a line on the display of a cathode ray tube that varied according to the intensity of the re-

turn. An image of the display was recorded on photographic film, which essentially meant that the varying intensity of the returns then corresponded to varying densities on the film (Figure 9). The film moved across the display to record successive intensity trace displays as adjacent

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positions on the film. Looking across the film from one edge to the other thus corresponded to the (slant) range dimension of the radar, and the ratio of the slant range imaged to the width of the film was called the range scale factor. Movement along the film reflected the azimuth direction and hence the along-track distance, with the ratio of the actual along-track distance to the length of film being called the azimuth scale factor. The ratio of these two factors, range scale

to azimuth scale, was called the aspect ratio; with the KP-II setup, the aspect ratio was anticipated to be about 6.9.²³

(S//FK) To make the recorder, Goodyear ordered from Westinghouse a special five-inch cathode ray tube with an electron gun that could withstand the anticipated shocks of launch. It had a single trace running across it, and the recorder imaged that trace down to about one inch on the data film. To keep the film drive uniform, free

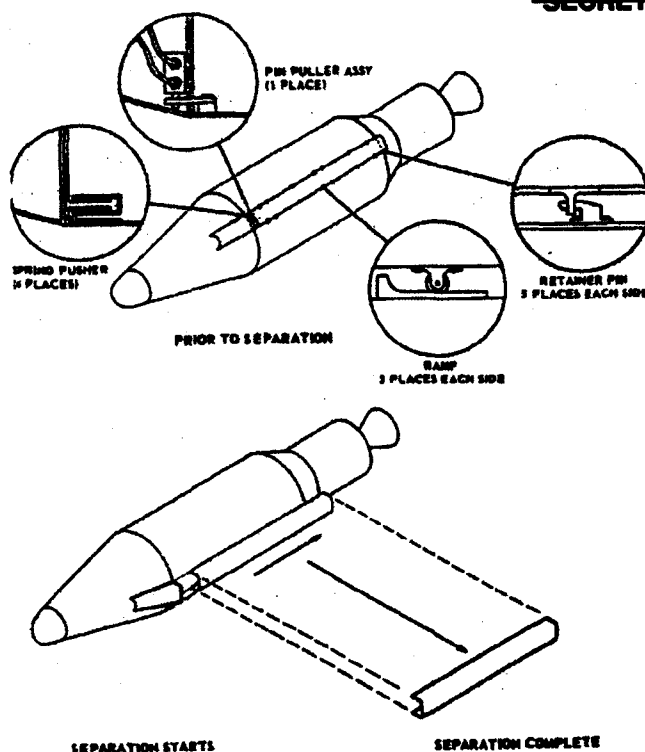


Figure 7. (S//FK) Fairing separation
Source: Lockheed, System Report 2, p. 1-14

* (S//FK) These are Lockheed's numbers, which are slightly inconsistent with those in [redacted] depiction in Figure 8. Lockheed, System Report 1, p. 18.

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of variations in tension and slipping, Goodyear engineers coated the master metering drum with silicone rubber in a specific angle of wrap. The recorder was custom-made for Quill from a special mold, nickel-plated and radio-frequency protected.

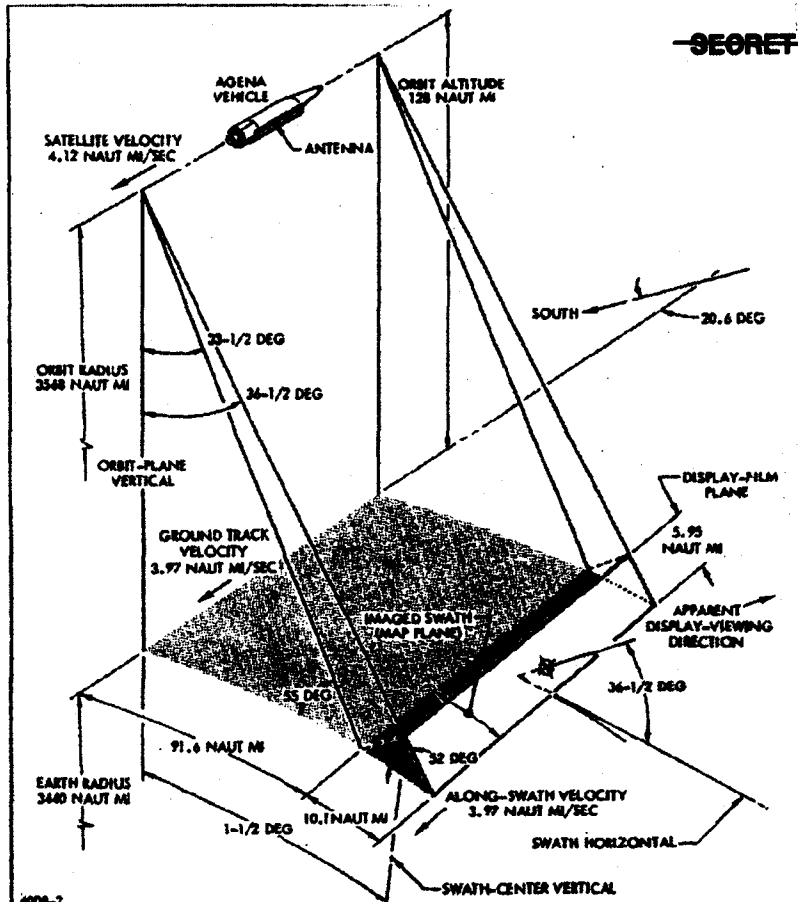
(S//FK) Radar data would be conveyed to the ground in two ways. One method was film, which was handled in two assemblies totaling 99 pounds (Figure 10). The recorder compartment housed the cathode ray tube and associated subsystems that allowed the film to record the images on the tube. The film itself was contained in a film-supply cassette. Exposed film went into an Itek take-up cassette in a General Electric re-entry vehicle (Figure 11) to be recovered by special C-130 teams (Figure 12). This approach to data recovery, incidentally, had also been mentioned in the earlier 1958 article in *Aviation Week*.²⁴

(S//FK) Data would also be transmitted to

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Figure 9. (S//FK) Signal film
Source: Lockheed, *System Report 1*, p. 144



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Figure 8. (S//FK) Imaging geometry
Source: [redacted] *Evaluation 1*, p. 18

the ground using an UHF wideband data link, and recorded at the Vandenberg, California, and New Boston, New Hampshire, tracking stations. The preflight engineering analysis seemed to consider this task simple and straightforward: "it is only necessary to provide a KP-II Recorder and a means of triggering it so that the telemetered video can be recorded."²⁵ Each location thus had a recorder identical to the one on board, together with control systems for establishing synchronized reception from the satellite.

(S//FK) In either case the product would be a film transparency. This film—the "signal film"—essentially recorded Doppler-coded data about ground reflectivity. Once on the ground, this information was converted into visual imagery using the "Precision Optical Processor"

including the recorder and the film-supply cassette, weighed approximately 99 pounds and was mounted in the conical section, which tapered 15 degrees from a five-foot diameter at its base, where it joined the barrel section, to its height of 32.95 inches. The film containing the raw data was stored in the nose cone, which incorporated the reentry capsule for recovery.²⁷

(U) Managing the Development

~~(S//FK)~~ Set up in this way, the Quill experiment could take advantage of the equipment and procedures for on-board photography and film recovery developed for the Corona program. In particular, Bradburn needed film cassettes, film recovery vehicles, and support for assembly, test, and checkout. In March 1963 these relationships came under the purview of Colonel Jack C. Ledford, an Air Force officer serving as assistant director of the CIA's Office of Special

Activities (OSA).^{*} Ledford recommended to his boss, CIA's deputy director for research, Herbert "Pete" Scoville, Jr., that the CIA provide contract support and security procedures for Quill. "Under the proposed plan, CIA would procure three (3) Corona Recovery Vehicles from General Electric, Corona Triple Prime Cassettes from Itek, and system assembly, test, and checkout by LMSC [Lockheed Missiles and Space Company] A/P [Advanced Payload] facility [in Palo Alto, California]. The completed system would then be sent by covert means to LMSC, Sunnyvale, where it would be mated and checked out with the Good-year Radar System."²⁸

~~(S//FK)~~ Scoville approved the recommendation, and OSA expended about [redacted] to

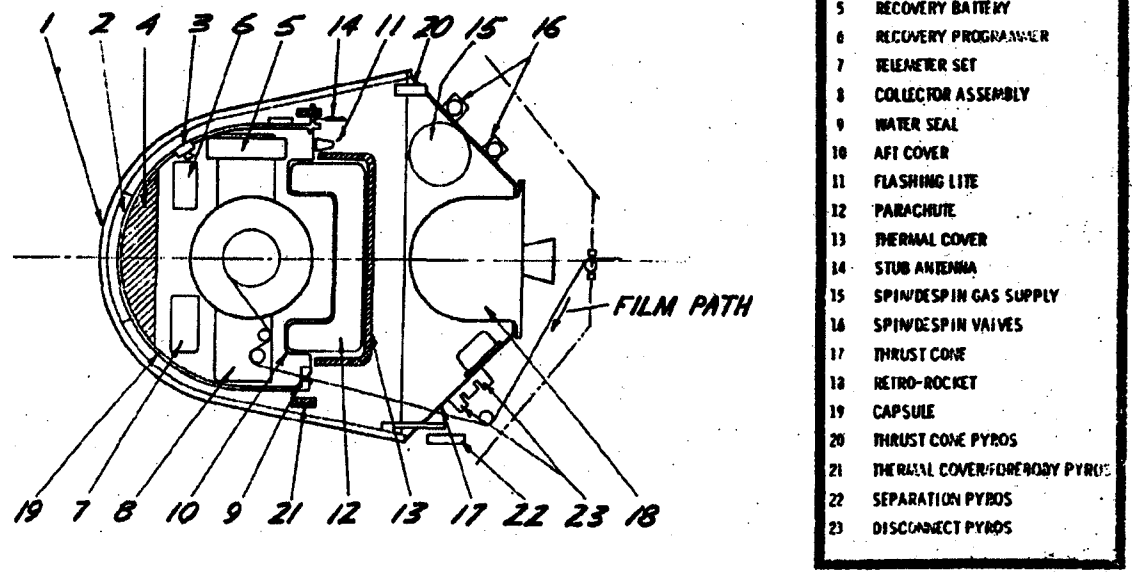


Figure 11. ~~(S//FK)~~ Film recovery system
 Source: Goodyear, *Engineering Analysis*, p. 6-50

^{*} ~~(U//FOUO)~~ OSA had been transferred to the Directorate for Research, and in March 1963 Scoville was head of that directorate. He was held responsible for CIA activities in support of the NRO, although he delegated the Program B job to a deputy and called himself the senior representative to the NRO. He left later in 1963, and his successor, Bud Wheelon, refused the Program B job entirely, leaving the title to the deputy DNRO, Gene Kiefer. Kiefer might certainly have called on Ledford's office for support.

acquire three film return vehicles from General Electric, take-up film cassettes from Itek, and services for checkout and assembly from Lockheed.²⁹ In addition to the procurement actions, the CIA had to develop procedures to keep information about Corona and Quill as separate (“compartmented”) as possible. Not all the government or contractor personnel working on Quill needed to know about the Corona program, nor did most

for establishing a payload laboratory for Quill, under compartmented security procedures, at the Lockheed facility where Corona space vehicles were processed. Integration of the Quill spacecraft components—including film cassettes, recovery systems, buckets, and waterseals—as well as any additional special tests that might be required for the Quill payload would take place in this facility. Normal weight and bal-

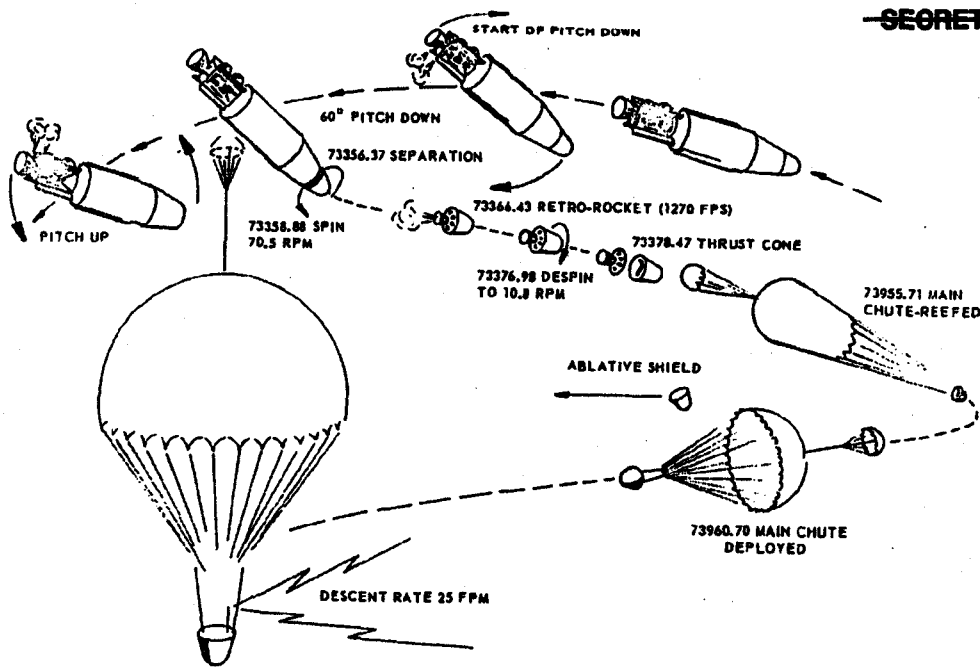


Figure 12. (S//TK) Capsule recovery process
Source: Lockheed, Project Report 2, p. 3-50

Corona people need to know about Quill. There were also different degrees of “knowing”: Those who worked with particular pieces of classified hardware might not need to know anything about the overall system or its mission, while several who needed that information did not need to know about specific subsystem capabilities or technical specifications.

(S//TK) By the end of March 1963 Corona security officers had developed a plan for keeping each program’s secrets.³⁰ The key difficulty was in finding a way to get hardware developed for Corona into the Quill program without directly associating the two. The plan called

ance tests and pyrotechnics installation would be conducted in the same facility used for such tests on Corona satellites, and a third facility also would also be available for other integration and test procedures.

(S//TK) The Quill program would be directed to obtain its recovery system from a group at Lockheed that had already been identified as specialists. The Lockheed manager for this effort would assemble a group of engineers to work in the Quill laboratory area ostensibly to develop designs for cassettes and waterseals; after a suitable period of time, their “plans”—actually drawings of the existing Corona subsystems—would

be presented and Bradburn would direct Itek to manufacture the desired items. The intended effect was to establish the cassettes and waterseals as hardware developed strictly and exclusively for Quill, and to disassociate Lockheed employees in the area from this sort of activity.³¹

(S//TK) The Quill contracts originally called for launching the first system in April 1964, but even Bradburn's tight focus and insistence on minimal technology development could not prevent delays. Bureaucracy was not the problem: Bradburn had few reporting requirements, good relations with Program B, and no awareness of any headquarters turmoil in Washington. The additional time was needed instead to resolve difficult technical and engineering issues. Like many program directors to follow him, Bradburn believed it was better to launch late with a successful satellite than on schedule with a failure, and so he determined that "emphasis will continue to be placed

on thorough testing to insure a good probability of success on the first flight."³²

(S//TK) At the end of May 1964 there was still considerable work left to be done. Environmental qualification testing had been completed for all radar components except the recorder. Several transmitter problems were identified during system-level Temperature-Altitude Simulation Chamber (TASC) tests, for which remedies had been designed but not verified. The flight vehicle was in an anechoic chamber for radiation

and emissions testing. Film recorders and signal simulators were on site at the Vandenberg and New Boston ground stations (known as "Cook" and "Bos"), and this equipment had been installed in T-29 and T-39 aircraft for conducting fly-by tests. The optical correlator was nearly complete at [redacted] and analysis of test films from the Goodyear recorders indicated that the design resolution was being achieved. A program review had been conducted by an ad hoc committee of Air Force

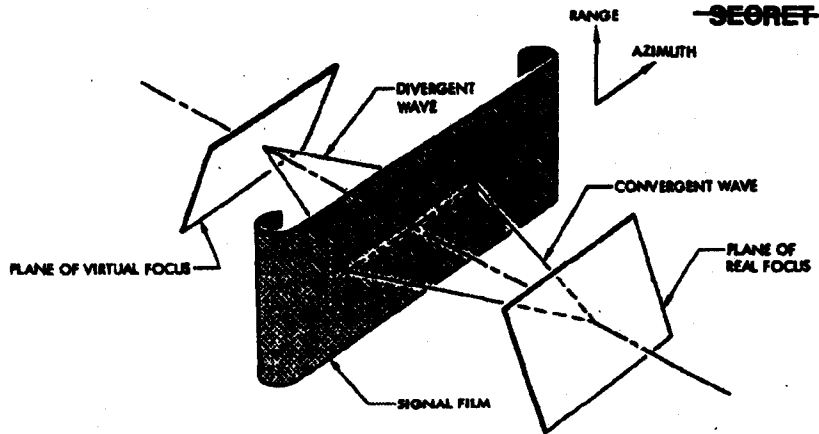


Figure 13. (S//TK) Focal plane relationships
Source: [redacted] Evaluation II, p. 259

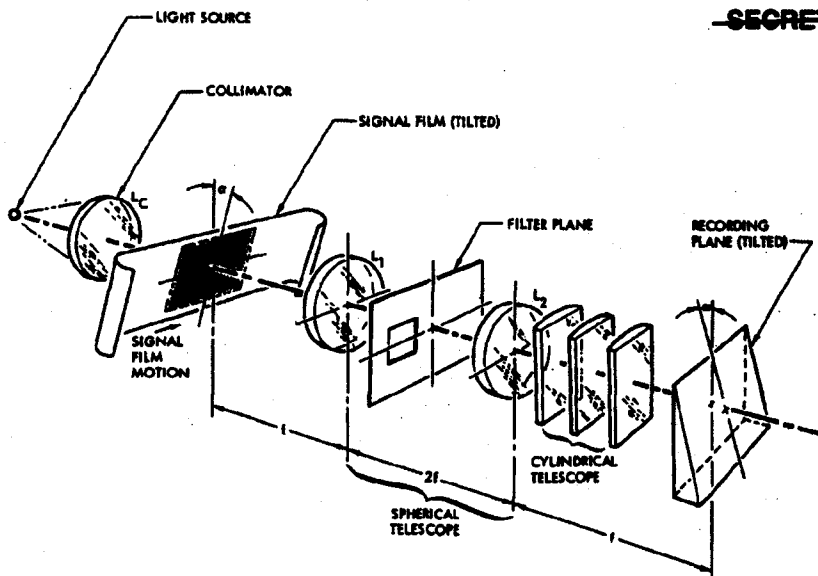


Figure 14. (S//TK) Anamorphic telescope processor
Source: [redacted] Evaluation II, p. 261

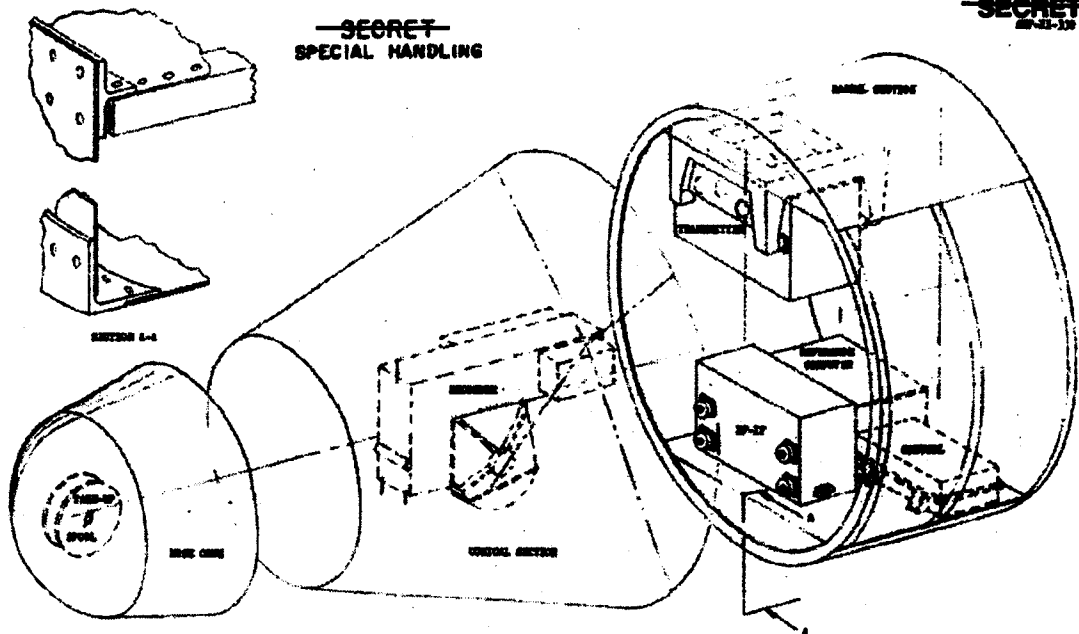


Figure 15. (S//FK) Agena nose assembly for Quill
Source: Goodyear, *Engineering Analysis*, p. 4-4

and Aerospace Corporation people drawn largely from a concurrent Hughes radar program (P-22) being conducted outside the NRO. The review found the program to be generally on track and suggested some changes in the wiring harness, lowering the operating altitude, and altering the approach to setting the pulse repetition frequency. The launch date at this time had been 5 August 1964; it was changed to 29 August, subject to success in TASC and anechoic chamber tests.³³

(S//FK) Steady progress was made over the summer of 1964. The anechoic chamber tests were completed, including all ascent and orbital sequences and full-power transmissions through the antenna, without signs of problems from electrical interference or interaction. Tests at the antenna range at Lockheed's Santa Cruz Test Base showed that the radar and the antenna were compatible, that the antenna did not distort the pulse, and that the slant range resolution of the system was better than 35 feet for the worst case (in-phase targets) and better than 25 feet for the best case (targets with 90 degrees of phase difference). Installation and testing of

equipment at the tracking stations had been completed; the optical correlator was complete and had been used to verify proper adjustment of the recorders by using test films processed by Air Force Satellite Photographic Processing Laboratory (SPPL) at Westover Air Force Base, Massachusetts. [REDACTED] had also completed a performance evaluation plan for the mission.

(S//FK) The Agena D upper stage had passed acceptance testing and was at Vandenberg, awaiting the payload. But transmitter/modulator problems continued to surface in system-level tests at altitude, and the launch date was delayed once again, to 2 November.³⁴ That date also passed as the radar transmitter failed yet again. The troublesome component was redesigned and, at last, showed no problems during TASC testing of the entire planned orbital operating time. It was shipped to Vandenberg in keeping with Bradburn's security procedure (*Table 1*), and by mid-December Quill was ready for launch (*Figure 16*)—eight months later than originally planned, but only 25 months after initial contract award.³⁵

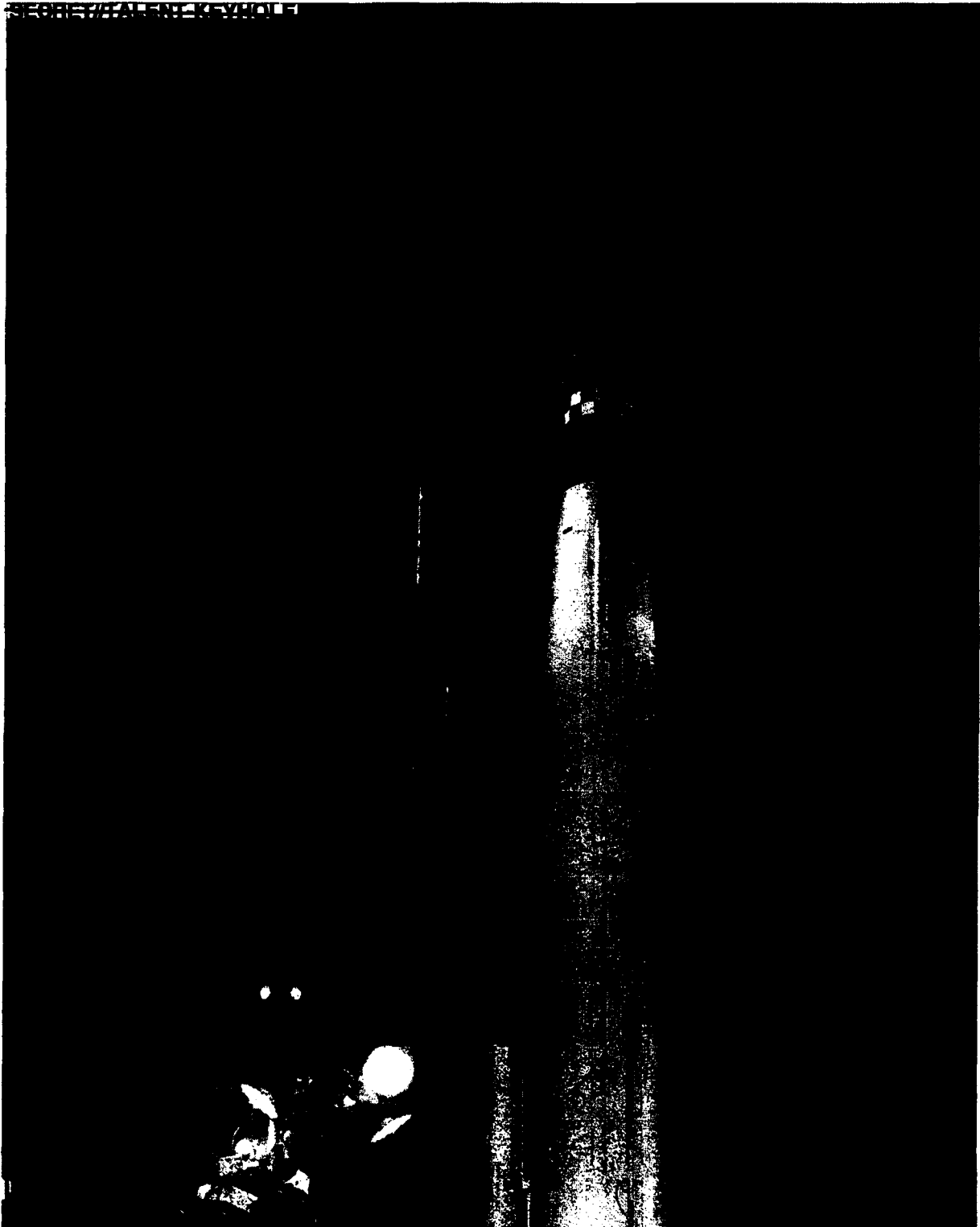


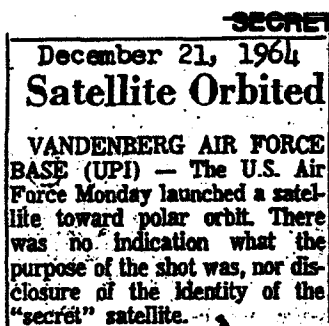
Figure 16. ~~(S//FK)~~ Quill awaits launch in this rare USAF photo.
(Thanks to NRO Archivist [REDACTED] for his efforts and persistence locating and documenting this photo.)

(U//FOUO) Orbiting the System

(S//FK) With Bradburn in command as launch control officer, on 21 December 1964 the world's first satellite-borne synthetic aperture radar was ready for launch from Vandenberg Air Force Base. Engineers had calculated a specific period during which the satellite should be launched (the "launch window") in order to minimize the amount of heat it would encounter on orbit. As time approached to within 10 minutes of the launch window, all systems were brought to readiness so that launch could occur within 30 seconds of command. Only official personnel were permitted within a defined area of the base during launches, but a civilian railroad track cut through the restricted zone, and, with only a few minutes to go until the launch window opened, range safety officers reported that a train was approaching. If it entered the exclusion area, safety regulations would prohibit the launch from continuing until the train was gone. The delay might be so long that the launch window would close, forcing the launch team to "unready" the Thor/Agena (which might involve several complex processes, such as removing propellants, preserving environmental conditioning, and recharging batteries, depending on when the next window opened) and await the next opportunity. Bradburn thus found himself assailed by demands that he launch immediately, ahead of the planned schedule, before the train came closer. He refused, not wanting to execute a contingency plan that was being made up on

the fly, and continued to wait for the appointed time. As it turned out, the train stopped while still outside the safety exclusion area, and the launch at 11:08 a.m. Pacific Standard Time proceeded according to plan.*

(S//FK) Knowing that the booster had worked, Bradburn headed north to the satellite control facility in Sunnyvale and soon learned that the Agena (international satellite designation 1964 87A) had been placed in a useful orbit (*Figure 17*) and was responding properly to commands. Word about the mission itself—whether the radar worked—would take several hours longer. The ground station at Vandenberg that had been set up to receive wideband data from the payload included a video display (cathode ray tube, or CRT, monitor) that would show the characteristic shapes of radar pulses being re-



*Figure 17. (S//FK)
Newspaper report
Courtesy [redacted]*

ceived and decoded if the Quill system were operating and transmitting. This equipment was operated by Goodyear, which for security purposes was referred to as the "Program Associate Contractor" (PAC). Later that day, at Sunnyvale, Bradburn received the message "PAC Room reports Code One"—radar returns from Quill were showing up on the Vandenberg CRT.

(S//FK) The mission, summarized in *Figure 18*, lasted only four days, as planned, before the unchargeable batteries ran out of power during orbits 72-73.³⁶ The radar operated 14 times in orbit,* between 0644 Coordinated Universal

* (S//FK) Bradburn, interview, and SAFSP Director's *Quarterly Report*, 30 December 1964. NRO headquarters in Washington, DC, was kept informed of major developments by secure teletype, a relatively slow and limited form of communication. When Bradburn decided not to launch early, a short message was cabled to NRO headquarters from Vandenberg saying "holding for passenger train." Then the launch window opened, range safety reported that the train had stopped outside the closed area, Bradburn gave the command to launch, and the Thor/Agena lifted off. The next cable to the NRO reported that Quill was in orbit, giving rise to initial concern in Washington—and continuing folklore—that Bradburn had disregarded safety and launched over the train. Bradburn recounted this event, without revealing the purpose of the launch, in "The Evolution of Military Space Systems," in R. Cargill Hall and Jacob Neufeld, eds., *The US Air Force in Space* (Andrews Air Force Base, MD: Air Force Historical Foundation, 1995), pp. 61-65.

Time (UTC) 22 December 1964 and 0618 UTC 26 December 1964, imaging the swaths of the northeastern and western United States indicated in *Figure 19 (also see sidebar)*. Data collected from the 14 radar passes were transmitted over a wideband (UHF) data link as they were obtained ("real time") to the Vandenberg or New Boston ground station in view. In addition, during the first seven radar passes data were recorded on film on board the satellite, and on 23 December during the 33rd orbit the reentry capsule was jettisoned and recovered. The film was flown to Westover to be developed and the developed film then flown to [REDACTED] [REDACTED] ran it through the specially made "Precision Optical Processor" (known as POP-1) and developed the image films. They were dried, bundled, and given to [REDACTED] to deliver to Los Angeles. The only delay in the process came when [REDACTED] flight was cancelled, but the key question had already been answered. [REDACTED] measured the azimuthal resolution to be 7.5 feet—the theoretical maximum from the 15-foot antenna—which immediately settled the question of whether there was a fundamental natural limit on SAR resolution from space.³⁷

~~(S//TK)~~ After less than two weeks of orbital decay the satellite re-entered the atmosphere at 1027 UTC 11 January 1965, on orbit 333. Several days earlier, Bradburn and his Program A superiors had already declared the mission a success. In his 30 December 1964 *Quarterly Report*, the Program A director said that "vehicle and payload performance were within acceptable limits on all parameters. . . . The radar maps . . . cover about 80,000 square miles. The resolution is better than 15 feet in azimuth and approximately 80 feet in ground range. . . . The volume of data is greater than had been anticipated. Technical evaluation has begun and will be completed in 90 to 120 days." In the meantime, "The second payload and Agena D booster are complete and are

being held at [Lockheed]. The second flight has been removed from the launch schedule pending detailed analysis of the first mission. The third payload, which consists of forward structure, radar components, and recovery subsystem, is near completion at [Lockheed]. There is no booster for this payload. . . . Recommendations for disposition of the remaining Quill hardware will be made in 30 to 45 days."³⁸

(U) Evaluating the Outcome

~~(S//TK)~~ The Quill team had wanted answers to several questions. Whether the satellite-based SAR would work was the main one, followed closely by others of practical engineering—how to make it work best. For example, it was helpful to experiment with the timing coordination among the functions of transmitting, receiving, and displaying the returns on the cathode ray tube:

The sequence of events was as follows: the radar transmitted a pulse, the receiver and recorder waited 25 microseconds, and the CRT was then swept for 73 microseconds; the system then repeated the cycle after an additional wait of 16 to 24 microseconds (depending on the choice of prf). . . . On certain occasions, the sweep started a few microseconds before the return from the near-range arrived; the imagery corresponding to these occasions lacks contrast and [a good signal-to-noise ratio] at the near edge, but is better at the far-edge. Conversely, the opposite occurred when the sweep was late in starting. On still other occasions, the sweep was begun as the return from the far-edge was arriving, continued while the instantaneous return power level passed through its minimum, and was almost completed by the time return from the near-edge began to arrive; under these conditions, the CRT was inoperative for the major portion of the return. . . .³⁹

~~(S//TK)~~ Engineers also wanted to describe the SAR's performance quantitatively, particularly

* ~~(S//TK)~~ The original mission design had called for 16 radar passes; available documents do not address the reduction. Goodyear, *Engineering Analysis*, p. 1-4.

-(S) Could Our Adversaries Detect Radar?

~~(S//FK)~~ Years later (see, e.g., Perry, pp. 35-37) a rumor began that Quill did not image territory outside the U.S. because the NRO feared international repercussions resulting from the radar emanations of its active imaging system. After the fact, DNRO McMillan said it was important: he wrote to the President's Foreign Intelligence Advisory Board (PFIAB) on 12 May 1965 that "radar operation during this mission was limited to Continental United States to insure availability of ground truth data, to obtain maximum quantity of all three types of products, and—since a radar sensor is an active device—to prevent possible complaints from foreign nations." There are, however, several inaccuracies in his presentation. (Notably, he stated that "the mission plan provided for simultaneous photography along the mission track by an RB-47," which would have required a truly remarkable aircraft.) Brockway McMillan, "Semi-Annual Report to the President's Foreign Intelligence Advisory Board on Activities of the National Reconnaissance Office," 12 May 1965 (TS/BYE), in ARC Job 200200001 Box 7 Folder 24.

~~(S//FK)~~ Quill was an engineering proof of concept, and so it was operated where engineering test data could be obtained—where there were devices on the ground to check the far field antenna pattern, pulse repetition frequency, etc., and reflector arrays to check impulse response. In addition, there were only seven active passes during which data could be collected on film, and they were conducted where data could be simultaneously transmitted by wideband relay to ground stations at New Boston or Vandenberg. Bradburn told this story quite straightforwardly, and I [Butterworth] probed him on the question. Furthermore, how might have "international repercussions" been imagined to arise? Who would be able to detect the signal and classify it and reach the right conclusions about its source and the country responsible for it? The radar could be operated for no more than five minutes at any one time and for no more than three orbits consecutively without courting catastrophic failure. It operated at an average power level of 230 watts, from an altitude of 130 nautical miles and hence a slant range of about 160 nautical miles. It traveled at a velocity of 25,500 feet per second (about four nautical miles per second ground track velocity). It illuminated a swath about ten miles wide. True, sidelobes could be detected as well as mainbeam signals (though not backlobes, as [redacted] discovered), but even so the chance of detecting the signal and capturing enough of it to reach accurate conclusions is vanishingly small. The USSR would have had no ephemeris data on the satellite adequate to do ground measurements of any possible emanations.

~~(S//FK)~~ [redacted]

with respect to its azimuth-direction behavior, and to determine how it had been limited by design parameters and in-flight performance of the payload, attitude behavior of the satellite vehicle, atmospheric conditions, and design and performance of the wideband data link. They were interested in describing and diagnosing any anomalous system performance, in collecting data on the reflectivity characteristics of target fields, in demonstrating the capability of ground equipment to record useful data through the wideband

data link, and in developing engineering data that would be useful in designing future aerospace radars. And they were most interested in seeing whether the analytic models derived from aircraft-borne SAR experiments, which had been used to prescribe and test satellite design, proved valid for operations in space.⁴⁰

~~(S//FK)~~ [redacted] engineers had designed ground-based tests to provide data for calibrating the SAR's performance. There were measurements at the earth's surface to check

the operation of the antenna after launch,* the transmitter pulse,† and ground surface and weather conditions. Complexes of radar corner reflectors were laid out in [REDACTED] their known cross sections and spacings could be used to calibrate estimates of the radar's range and azimuth resolution, sensitivity, and dynamic range. Because Quill's radar antenna was fixed, [REDACTED] engineers had to wait until they had obtained good ephemeris data and then scramble to move some of the corner reflectors to keep them in the satellite's field of view.⁴¹

(S//TK) These evaluations used visual images produced from the recorded data in the sequence outlined in *Figure 20*. First, the film of the video data was developed by the SPPL, using an approach aimed at maximizing the dynamic range of the recorder.‡ The [REDACTED] team then used their precision optical processor to convert the data on the film into visual images. The highest resolution (and the best dynamic range) was obtained directly at the processor output, on photographic transparencies. The original output transparencies were then magnified 2.6 times and recorded as either paper prints or positive transparencies, neither of which was suitable for detailed analysis:

The paper prints . . . have a resolution capability of perhaps 6 lines per mm; at the scale factors corresponding to the 2.6:1 enlargements, this poor resolution completely dominates the

quality of the imagery. The resulting ground-range resolution is of the order of 90 to 100 feet. The degradations in the positive transparencies . . . are not as severe. In either case, imagery to the scale of the 2.6:1 enlargements is useful primarily for orientation and descriptive purposes only, and not for detailed study of the target complexes. Detailed examinations require the use of enlargements of greater magnification, the use of the original output transparencies, or in special instances the observation of the optical output of the processor prior to recording.⁴²

(S//TK) The results showed the experiment to have been a great success. The radar worked and met the goal of 10-foot azimuthal⁴³ resolution.** It had illuminated somewhat more than 100,000 square miles of terrain, almost 80 percent of which yielded usable images. Three-fifths of the images were of the best quality that the system could produce; the rest were degraded for testing or by slight errors in setting the pulse repetition frequency. Only four percent were lost unintentionally.⁴⁴

(S) As expected, the smooth trajectory of the satellite allowed it to provide relatively fine detail without the complex systems needed on aircraft to compensate for platform motion. In effect, "satellite borne systems are not subject to the resolution limitations normally imposed

* (S) These were measurements of the azimuth beam pattern for the purpose of confirming that the antenna's far-field pattern remained correct after launch.

† (S//TK) "It was possible to detect and record the transmitter pulse, after it had propagated one-way from the satellite to the earth's surface, by detecting emissions via the sidelobes of the radar antenna pattern and recording these emissions on photographic film. This was done on several passes when the satellite was within line-of-sight of [REDACTED]

Evaluation I, p. 9.

‡ (S//TK) "The flight system employed a [cathode ray tube] with a P-11 phosphor and a transfer lens which imaged the line trace of the tube at a 2:1 demagnification onto Kodak SO-266 blue-sensitive film. The film was developed in D-76 developer by SPPL. The dynamic range of the recording system in the flight vehicle was measured from test films generated prior to flight. . . . The value of the dynamic range of the flight recorder was about 19.5 db." [REDACTED] *Evaluation II*, p. 256. But cf. Lockheed, *System Report 2*, p. 4-11: "The video data recorded in the satellite and in the ground based recorders was recorded on 70 millimeter Eastman Kodak film, S. O. 119. The recorder CRT sweep covered a width of approximately 27.5 millimeters."

** (S) Referring to the performance of a SAR in terms of "resolution" is a conventional solecism; usage today tends more often to the technically accurate "impulse response," or "IPR."

~~SECRET//TALENT-KEYHOLE~~

1.6 System Performance - The system performance was faultless throughout the orbital mission, until battery depletion on Orbit 72 - with the exception of minor unexplained voltage disturbances on Orbits 8 and 9. This section presents the significant payload operating information, radar imagery samples and discussions of the payload performance, preceded by a brief summary of system parameters and performance.

Launch

Date: 21 December 1964 Time: 1908:56Z

Location: Launch Complex 75-1-1, Vandenberg AFB

Vehicle: LV-2A #425 SS-01A #2355

<u>Orbit</u>	<u>Predicted</u>	<u>Actual</u>
Period (MIN)	89.44	89.66
Perigee (N.M.)	130	135.82
Apogee (N.M.)	154	157
Inclination (deg.)	70.0	70.11
Eccentricity	.003	.0036
Active Orbits	65	73
Recovery	65	33
Payload Operations	13	14

Area recorded as fine resolution radar imagery:

approximately 70,000 square miles (nautical).

Figure 18. (S//FK) Summary mission data

Source: Lockheed, *System Report 1*, p. 23

by platform instability in aircraft."⁴⁵ Slant-range resolution (which was not a design goal) was 45 feet, which at the Agena's depression angle provided a ground-range resolution of about 75 feet.* The imagery showed several terrain and cultural features that held promise for strategic reconnaissance. Weather conditions did not seem to have affected the quality of the system's im-

* (S//FK) "Range resolution . . . was limited by the bandwidth of the electronics, which had been patterned after the AN/UPQ-102 radar system for reasons dictated by expediency; the most optimistic estimate of achievable slant-range resolution was of the order of 36 feet, which in turn implied a ground-range resolution of 60 feet at the design depression angle. Improvement of the range resolution to make it comparable with the expected azimuth resolution was not warranted, since it would not have affected the demonstration of the synthetic-aperture feasibility, and would have entailed considerable expense and delay." Lockheed, *System Report 1*, p. 33.

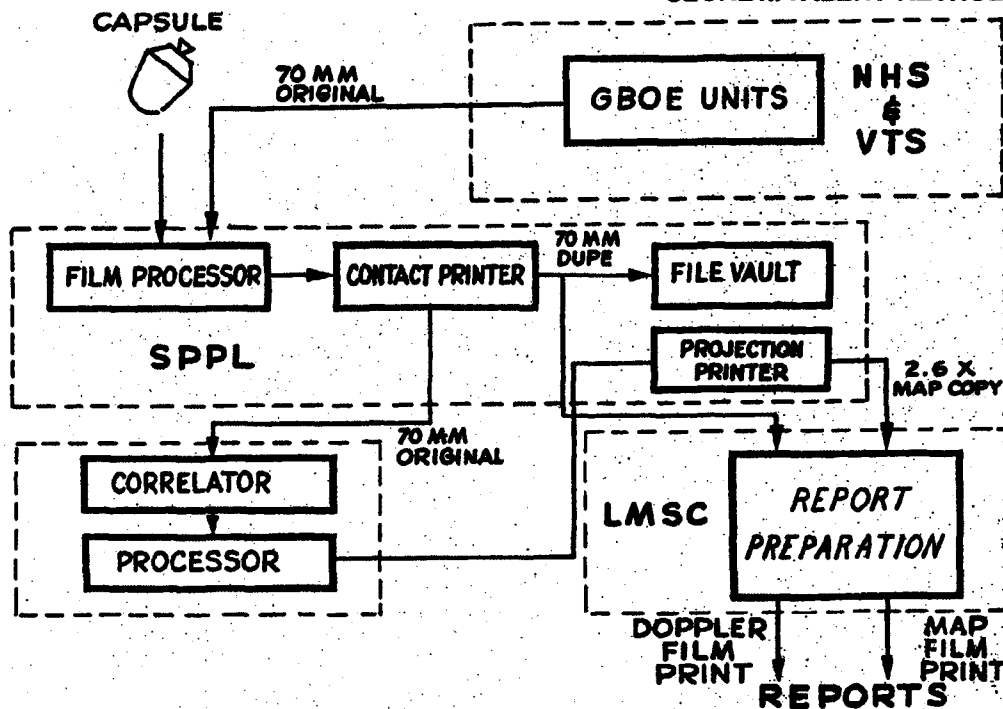


Figure 20. (S//TK) Image processing sequence
Source: Lockheed, System Report 2, p. 4-2

ages except for a brief area of intense rainstorms, and even then the imagery revealed the underlying structure.

(S) Quill answered dozens of technical and engineering questions. It showed that analytic models based on aircraft operations worked well for satellites. It showed that imagery processed from the transmitted data was only slightly degraded compared with pictures made using the recovered film. It showed that images obtained from orbit could fairly well match those from aircraft radars using similar technical parameters. It proved that ambiguous target indications could be minimized and that the slight inaccuracy and instability in the satellite platform could be compensated electronically. It also sampled the average radar reflectivities of several different types of terrain.

(S//TK) Altogether, in the words of ██████████ assessment, "the orbital flight satisfied the primary program objective by demonstrating that a satellite-borne synthetic-aperture radar system

could generate a fine-resolution image of a portion of the earth's surface; all secondary objectives also were met."⁴⁶ The Lockheed assessment added that the system proved its expected ability to produce radar imagery of a consistently high quality by day, by night, and through a variety of weather conditions; it also observed that the conditions that prevailed in most of the swath areas would have prevented successful photographic or infrared imaging (Figures 21-25). Furthermore, the experiment did not produce any evidence of phenomena that would prevent future systems from realizing azimuth and ground-range resolutions on the order of 10 feet.⁴⁷

(S//TK) The evaluation reports from ██████████ Lockheed, and Goodyear all exuded optimism and expectancy: Quill had been highly successful and the path to doing more—a further experiment, even an operational system—seemed clear. The ██████████ report recommended that "designs of future systems be based on the type of analytic model used successfully for this design,"

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that "proper use be made of radar equipment in manned aircraft for the purpose of collecting further data and testing configurations which are applicable to future satellite systems," and that various engineering adjustments be made to "future orbiting systems."⁴⁸ The Lockheed report agreed and recommended further that "future experimental orbiting systems incorporate power sources which are adequate for extended-duration missions, as required for operational applications."⁴⁹ Goodyear engineers undertook additional test work, demonstrating the value of improved potting techniques for the transmitter and modulator components of the radar as well as the ability to improve significantly the dynamic range of the recorded data by reducing film base density and reducing the recorder lens stop.⁵⁰

(U) A [REDACTED] Pause

~~(S//TK)~~ Yet Quill's seed fell on stony ground. Bradburn asked another officer in [REDACTED] "What do you do when you come up to bat, and, the first time, you knock a ball out of the ballpark, what do you do then?" The reply was, "Well, Dave, I think you go down and sit on the bench."⁵¹ On 5 January 1965 Bradburn gave NRO Director McMillan a "quick-look" briefing on the P-40 mission and got agreement that the second vehicle would be removed from the launch schedule, pending further recommendations to be made in February. On 11 February, several weeks before contractor evaluations of Quill's product and performance were completed, Major General Robert Greer, director of Program A, cabled McMillan that the Quill contractors recommended flying the second mission later that fall, but that he, Greer, did not agree. "In my opinion there is no need for more flights to show feasibility as such. We should have a definition of the desired operational use before we schedule any more launches. . . . The factors which need to be examined now do not require satellite flights." McMillan agreed, and the remaining hardware was placed in storage pending completion of the

Table 1. ~~(S)~~ Quill security procedures (payload equipment flow)

1	Goodyear Aerospace Corp. fabricates and assembles radar payload, test equipment, and ground data handling equipment.
2	Shipped to LMSC by military air as arranged by SAFSP; departs Litchfield Park NAS, Arizona, and arrives Moffett NAS, California, adjacent to LMSC; USAF or LMSC Quill-cleared courier accompanies shipment.
3	Arrives Moffett NAS; transferred to Navy van and driven to Quill approved area in [REDACTED]; courier accompanies equipment until it is secured in [REDACTED].
4	In covert area, [REDACTED] equipment undergoes component, circuitry, and bench checks; performance tests, acceptance tests, and necessary modifications accomplished.
5	Transferred in LMSC van to Complex C-12, Area 40, [REDACTED]; undergoes systems test with Agena vehicle; USAF acceptance procedures accomplished (DD250).
6	Shipped separately from Agena vehicle to a Quill-approved area in [REDACTED] Vandenberg AFB; transferred by LMSC van with Quill-cleared courier; mated with Agena vehicle and undergoes final systems run.
7	Transferred to launch pad for R-Day checks, countdown, and launch.

~~SECRET//TALENT-KEYHOLE~~

Source: "Quill Supplement: Covert Program Security Plan," 2 March 1964

report of an evaluation committee commissioned by NRO headquarters.⁵² Program A's financial summary showed a total of [REDACTED] in Quill's budget (Table 2).

~~(S//TK)~~ In his Program A *Quarterly Report* for June 1965—his last as director—Greer reported that a further [REDACTED] had been provided to [REDACTED] to complete its studies, but that otherwise SP considered the Quill program completed.⁵³ At the end of the year Greer's successor, Brigadier General John L. Martin, reported that the DNRO had approved a further [REDACTED] for radar and associated tape recorder work (Table 3 shows

contracts definitized at that time). The RCA and Ampex tape recorder studies showed that the state of the art did not provide adequate bandwidth for existing radar applications; Goodyear completed a 100-hour life test of the Quill radar; Hughes produced and tested a space-qualified antenna, and also expanded the radar system design to a dual mode capability (high and low resolution); and Airborne Instrument Laboratory's research provided a feasible new radar system design as well as ongoing study of radar target signatures.⁵⁴

(S//FK) Apparently none of this work went any further, and references to follow-on studies, operations, and plans disappear from the SP *Quarterly Reports* for several years after 1966.

studies, intended to be conducted in parallel with the engineering demonstration, were not decisively concluded. Thus by 1965 the NRO had completed an orbital demonstration, but no agreement had been reached that the proposed application, bomb damage assessment, or any other application, was sufficiently attractive to proceed."⁵⁶

(S//FK) Bradburn helped where he could. Through his efforts, [redacted] got new aircraft for further research and development, and in spring 1965 he took [redacted] to the National Photographic Interpretation Center (NPIC) to educate and help the photointerpreters make use of radar images. [redacted] met with little success: the photointerpreters generally picked

~~SECRET//NOFORN~~



Figure 21. (S//FK) City/rural contrast (BIF-555-DP-12782-89) Courtesy [redacted]

Three years later, in 1969, the NRO reported to its Executive Committee (ExCom) that "NPIC evaluated the [Quill] imagery, stated it was capable of providing useful intelligence, and recommended further research and development."⁵⁵ And in 1972 an "NRO Position Paper on the NRO Satellite Program" stated that after Quill's flight, "it was concluded that no further satellite experiments as such should be conducted; instead efforts should be made to define precisely the system application desired, and then the development of the actual system should proceed. The system appli-

up the radar images only to throw them away."⁵⁷ In the summer of 1965, Bradburn left Program A to attend war college; he returned a year later at the request of Program A's director Bill King, but had little opportunity to work on radar.⁵⁸ The *Quarterly Report* for 30 June 1966 advised that in July project responsibility for Quill would be transferred from the sigint office [redacted] to Lt. Col. Bradburn, working in the applied research and advanced technology office (SP-6) under Colonel Lew Allen.⁵⁹ The next *Quarterly Report* noted that SP-6 had a deficit of one officer: "Lt.

Table 2. (S//TK) Quill budget [REDACTED]

Spacecraft	FY63	FY64	FY65	Total
White LMSC-800	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
Satellite Control Peculiar	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
Black Goodyear - 7712	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
Black Recovery Equipment	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
*THOR Booster	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
THOR Launch Services	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
AGENA Vehicles	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
AGENA Launch	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
Satellite Control, Common & Dev	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
Total	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]

*The THOR booster for FTV 2356 has been released to be reprogrammed into a future [REDACTED] launch and credit for one THOR will be given to [REDACTED]. Source: SAFSP Quarterly Report, 30 June 1965, NRO history files.

nature and is not to be considered in any sense as an operational prototype or the initial step of an operational system development. . . . The request for proposals should make clear the experimental, rather than the operational prototype or system nature of this effort."⁶³ The director of intelligence for SAC offered to help evaluate the Quill imagery and the NRO staff responded affirmatively, noting that an engineering evaluation was under way by contractors, that an intelligence evaluation was being established, and that

Col. Bradburn transferred to sigint on 2 August. SP-6 not now manned to accomplish work in radar and elint technology."⁶⁰

(S) Reflecting on the question of Quill's singularity, Bradburn reiterated his objective: to show that satellite-based SAR imagery could help provide post-strike reconnaissance (bomb damage assessment) for SAC. That objective was accomplished and briefed to SAC. When SAC officials asked Program A's director, John Martin, "What's next?" Martin said: "Send money."⁶¹

(S//BYE) Cancellation of further Quill flights gave SP a big boost in its annual "cost reduction" report—[REDACTED], more than two-thirds of the total [REDACTED] claimed for FY1965 and earlier. "We are pleased," stated SP Director Brig. Gen. Martin, "to report that these reductions have been made without adverse impact on mission performance."⁶² The NRO had demonstrated the technical feasibility of an all-weather, day-night imaging system that could meet an important SAC need; if SAC wanted one, then SAC would have to create a program to develop it. Director Charyk had been emphatic in his cable of authorization: "The effort is to be strictly experimental in

"a separate analysis of the Quill product from the SAC operational viewpoint would be of great value to us in the overall evaluation of the system."⁶⁴

(S) Some of SAC's intelligence officers favored going ahead with a procurement,⁶⁵ and during 1965-66 they continued to visit Program A to stay up to date on the continuing analyses of Quill and imaging radar technology. The SP Quarterly Report for 30 June 1966 reported tersely that "on 26 May SAC briefed SAFSP (Office of the Secretary of the Air Force for Special Projects) on their desired radar system for post attack reconnaissance. No requirement for this system has yet been established."⁶⁶ Perhaps SAC delayed in the hope that some other



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Figure 22. (S//TK) Phoenix, Arizona. Image taken on pass 9, northbound, at night (1:12 a.m. Mountain Standard Time, 22 December 1964). Weather: clear, temperature 46 degrees Fahrenheit, dew point 43 degrees, visibility 15 miles.

~~(S//TK)~~ "The route of a major expressway (1) can be followed from the lower left around the most built-up portion of the city and up to the airport (2), the large return-free area at the upper right. Because the radar [pulse repetition frequency] was not matched to the beam illumination at the time, the airport edge of the swath fell in a poorly illuminated area near the edge of the beam. The railroad paralleling the left side of the airport does not stand out as do tracks across rural areas, but its course toward the lower right corner is marked by types of construction (3) that give strong returns. Similar returns accompany a diagonal branch line (4) ending at the lower center. The dark lines (5) that go irregularly up the center and along the base of the hills are canals." ██████████ *Evaluation I*, p. 30.

budget would support the desired development; perhaps its officers did not get Martin's message as clearly as Bradburn did; perhaps they thought

the mission was well ensured by the new SR-71 reconnaissance aircraft; or perhaps something entirely different accounts for the command's

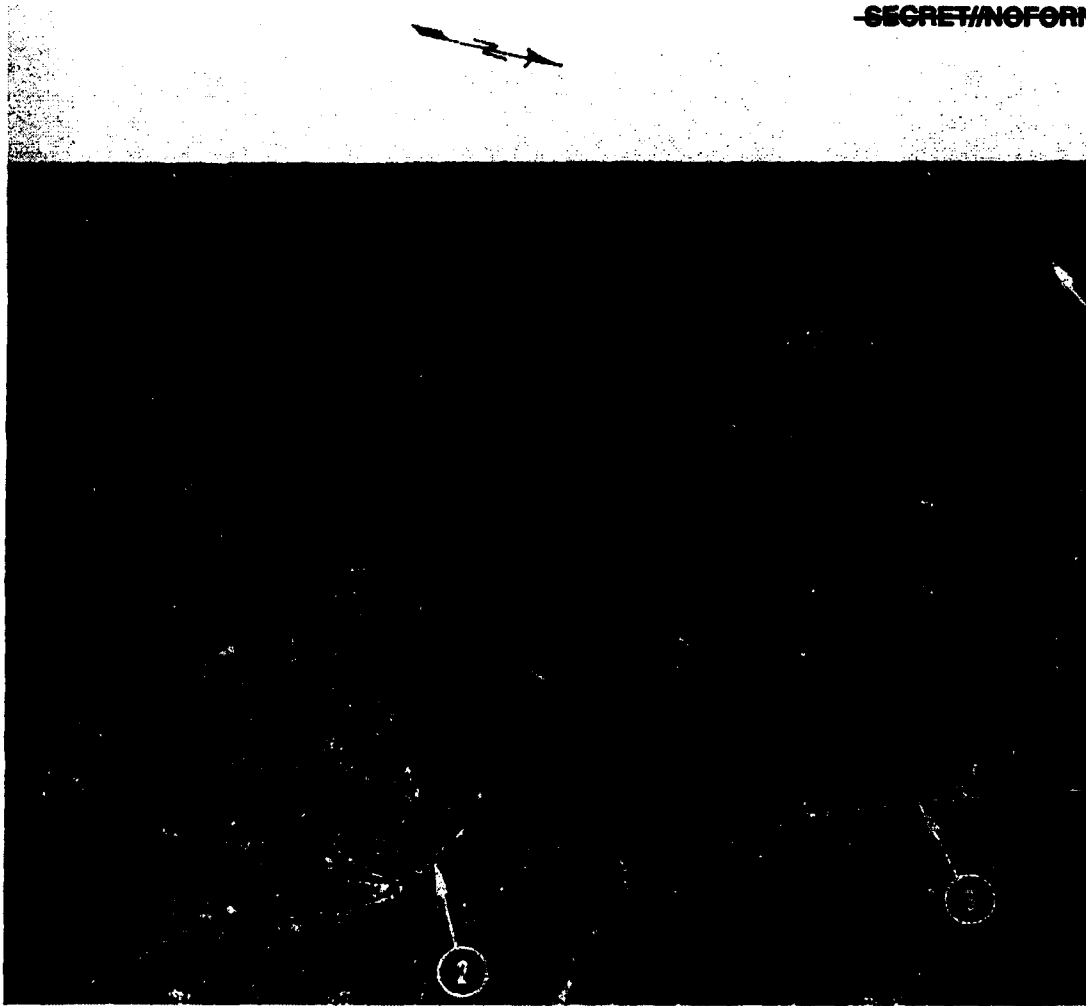


Figure 23. (S//FK) Richmond, Virginia. Image taken on pass 14, southbound, during daytime (11:06 a.m. Eastern Standard Time) on 22 December 1964. Weather was overcast with tops of clouds at 2,500 to 4,500 feet.

~~(S//FK)~~ "Several road and railroad bridges cross the James River (1) and a mile-long elevated section of railroad (2) parallels the river near the center of the radial system. Again, the association of strong-return systems with railroad routes can be seen (especially [3]). Street, cultivation, and drainage patterns are recognizable." ██████████ *Evaluation I*, p. 33.

lack of initiative for further program development at that time.⁶⁷ Or perhaps the command had in fact pressed for an imaging radar satellite through different channels. Dr. Alexander Flax, who became director of the NRO on 1 October 1965, recalled seeing a statement of need to this effect coming through non-NRO channels when he was serving as Assistant Secretary of the Air Force for Research and Development. He passed

it forward, without comment, to the Joint Chiefs, and did not hear about it again.⁶⁸

~~(S)~~ Perhaps the NRO should have done more as well; it was responsible for developing intelligence collection satellites, and Quill had already demonstrated a resolution almost three times better than the early Corona cameras. Why was there no second, improved version of Quill? In part, even some officers in Program A thought

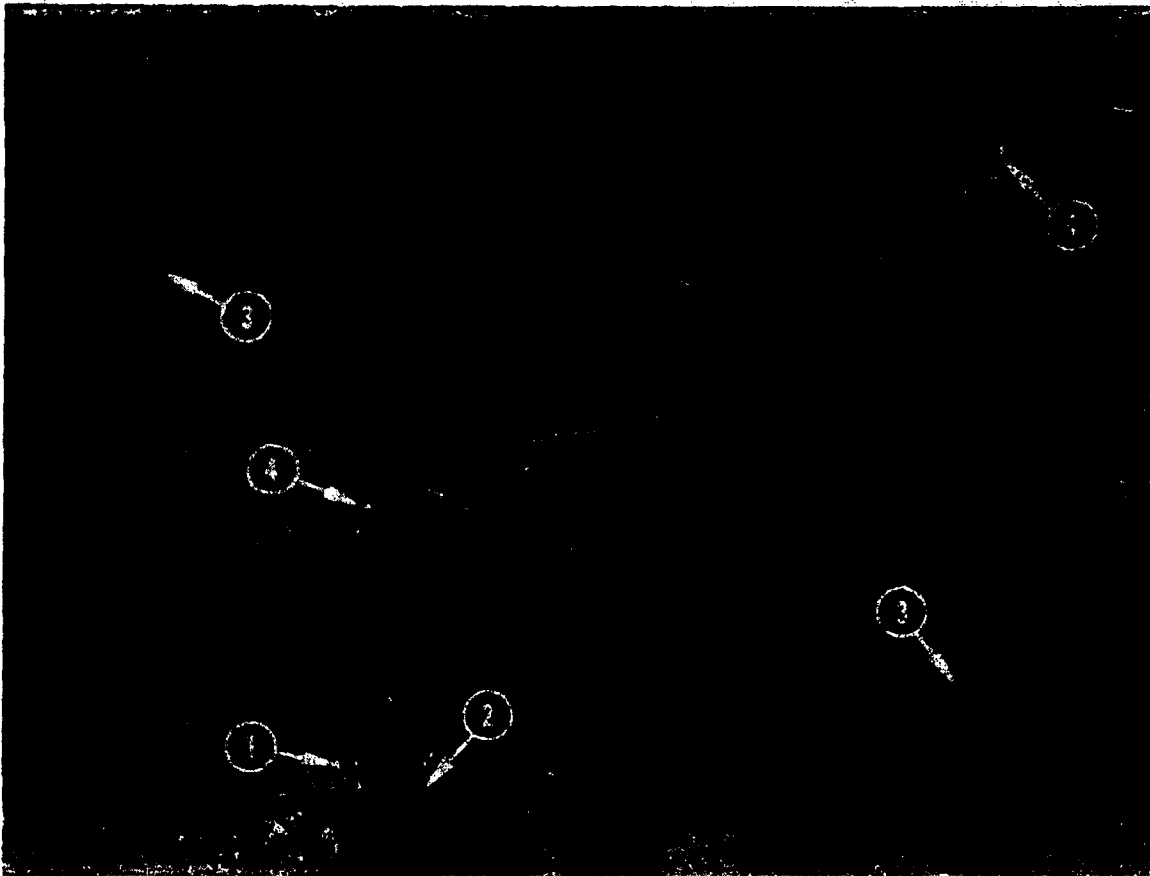


Figure 24. (S//FK) Wurtsmith Air Force Base, Michigan. Image taken on pass 30, south-bound, during daytime (10:57 a.m. Eastern Standard Time) on 23 December 1964. Ground is covered by snow at least two inches deep; area 1s in fog, sky obscured, wind calm, one-mile visibility, cloud tops at 9,000-10,000 feet.

(S//FK) "This SAC facility stands out unmistakably from its wooded surroundings between Michigan's Van Etten Lake and the Au Sable River. Parked aircraft are likely to be responsible for the eight or more bright returns located on the rectangular paved area (1), but the rapid-egress parking spur (2) contains only one or two aircraft-like returns. Many roads, including some little-traveled ones, are seen as narrow gaps in the tree cover, although some such gaps are power-line clearings. Two large areas of cleared land (3) show where the forest has given way to farmland. . . Two dams (4) and the reservoirs they form are readily detected and identified. No power lines are seen emanating from the hydroelectric plants here . . ." ██████████ *Evaluation I*, p. 37.

there were good a priori reasons to discount the value of an imaging radar satellite, regardless of Quill's success. Pointing to its "small area coverage, narrow bandwidth, and low resolution,"

they argued that it could not serve either search or indicator monitoring purposes. "Only in the area of Post Strike Assessment can radar be expected to be satisfactory . . . whether a radar PSA

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Figure 25. (S//TK) Point Reyes, California. Image taken on pass 16, southbound, during daytime (11:05 a.m. Pacific Standard Time) on 22 December 1964. Weather conditions: heavy rain, scattered clouds 700-1000 feet, heavy overcast 1400-2500 feet, clouds in layers to 35,000 feet.

~~(S//TK)~~ "Intense rainfall was occurring locally in the area While the clouds themselves are generally not imaged, the occasional regions of dense rain (see arrow) scatter considerable signal back to the radar, causing cloud-like forms in the image. Inspection of the film shows that the ocean wave-structure patterns can be observed even in the densest parts of the rain-returns. Furthermore, although the raindrops both back-scatter and attenuate the radar waves, hence reducing the illumination at some greater slant range, no shadows of these rain cells have been noticed in the imagery. Of interest is the alteration of the wave pattern in the shallow water off the beach, and its diffraction around the point and into Drake's Bay." [REDACTED] *Evaluation I*, p. 77.

system is practical as an operational system remains to be seen. There are practical difficulties and there exists doubts [sic] as to whether such a system is the best way to learn, quickly and surely and inexpensively where the bombs hit."⁶⁹ According to Bradburn, the NRO saw no point

in conducting further demonstration missions. In Flax's view, the relationships among radar parameters and image interpretation needed to be explored and understood more systematically, and he insisted that Program A establish a program of experiments.⁷⁰ The NRO together with

the Air Force and CIA continued to fund ground-based research at a low level, but none of those efforts involved orbital tests.*

~~(S)~~ Reflecting on the effort later, Flax said that the real difficulty was opposition from the intelligence community.⁷¹ There was strong support from defense leaders for proceeding with a radar satellite program: SAC was favorably impressed by Quill, and the new director of defense research and engineering, John S. Foster, Jr., urged Flax (and Flax's successor, John McLucas) to build another satellite.⁷² Flax also thought it would be a good idea, but some in the CIA were resistant.[†] Quill had shown that satellite-borne SAR imagery was feasible, but the intelligence community thought and worked in terms of optical imagery, and in those terms a radar satellite would not be useful until it attained much finer resolution. A system that was worthwhile for tactical bomb damage assessment was not justifiable as a national intelligence asset. Officers in CIA's science and technology directorate declared that other technologies might be developed that could provide better images; yes, Flax replied, but SAR is a technology that we know how to do now.

~~(S//FK)~~ Still, Flax did not believe he should press the matter in the absence of agreement, in the form of requirements, from the intelligence community. Mindful of the programmatic strife under his predecessor, Brockway McMillan, and working under a new NRO charter intended to repair that damage and prevent its recurrence,⁷³ Flax paid attention to bureaucratic diplomacy,

taking care to base his decisions and recommendations on solid technological ground.⁷⁴ In doing so, Flax proved far more than a mere barometer of consensus; he successfully opposed the strong preferences of Program B, for example, in canceling the CIA's independent efforts to build a launch vehicle, in dividing program management responsibility for a new photo-reconnaissance system (Hexagon), and in choosing the molniya orbit recommended by Program A for a new [REDACTED] program. The SAR satellite proposal, however, was not a question of how to do something but whether something was worth doing in terms of intelligence. And Flax believed that the NRO director should not under these circumstances unilaterally overrule the nation's premier intelligence agency. That action would have to be taken by the higher governing body that oversaw NRO programs, the executive committee (ExCom), and to that end Flax raised the issue with Deputy Secretary of Defense Cyrus Vance, the ExCom's chairman. Vance would also have heard from Foster, whose job as Deputy Director, Research and Engineering (DDR&E) included monitoring NRO programs and providing advice directly to the deputy secretary of defense. Flax thought Vance was impressed somewhat with the SAR technology but evidently did not feel strongly enough to press the issue with the new director of central intelligence (DCI), Richard Helms. Helms, in turn, came from a background in traditional intelligence, was not personally attuned to space technologies and satellite reconnaissance, and in this matter followed

* ~~(S//FK)~~

† ~~(U//FOUO)~~ CIA's deputy director for science and technology, Albert D. "Bud" Wheelon, was not among them. He applauded the experiment and criticized Bradburn only for not going ahead to do more. (Interviews with both, May 2000, Los Angeles and Montecito CA.)

the recommendations of Program B.

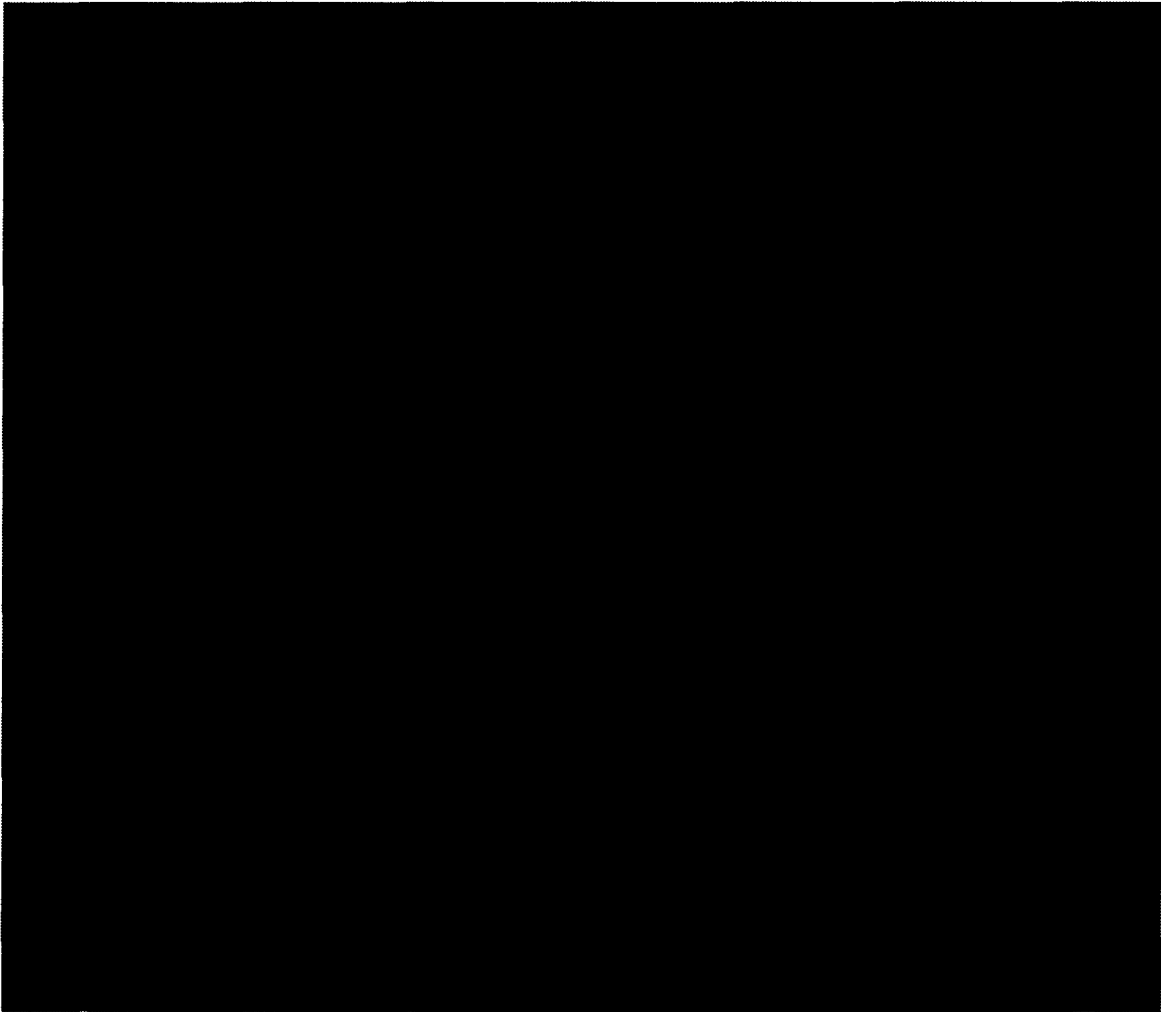
~~(S)~~ Flax was left with pursuing a technology development program in an effort to persuade the intelligence community that there really was information valuable for intelligence purposes in radar data. The prospects, he thought, were not without hope. In practice, the standard to be met was radar imagery on a par with imagery obtained from optical systems—an order-of-magnitude improvement. A major advance was needed; evolutionary improvements in film emulsions, platform stability, signal timing, recorder dynamic range, and the like would not be enough to bring a 10:1 improvement in resolution. Bradburn predicted that such a gain would take considerable time, perhaps ten years.

~~(S)~~



(U) Conclusion

~~(S//FK)~~ No physical artifacts and few documents remain from the Quill experiment. The Thor/Agema launch vehicles were recycled into the Corona program, and the remaining radar equipment was broken up and destroyed. "It was heartbreaking," [redacted] said. "One time," he went on, "someone came [to Litchfield Park] and had the right kind of credentials, and wanted to know if any hardware existed from the KP-II program. I said no, all had been destroyed. What did you want to do with it? He said they wanted to put it into the Smithsonian museum. Sorry, all gone. Unfortunate that the program has remained



so highly classified. But that's the way it is. I'd like to be able to tell my son what I had accomplished and what I was a part of, but I can't and I won't."⁷⁷

~~(S)~~ Gone, too, was a time of exploration and innovation that today seems as remote as John F. Kennedy's Camelot. Outside the Washington NRO headquarters, there was close and willing cooperation between Program A, the Air Force component of the NRO, and the CIA component, Program B. Government authority was vested in a project officer, Major Bradburn, who possessed both the relevant technical expertise and development experience. Only one management layer, Bill King, separated Bradburn from the director of the NRO, who became involved only to approve the project (and receive King's

quarterly reports). Being himself knowledgeable in the technical field, Bradburn used informed peer review to select the contractor team, which worked intimately together and with him to ensure that vehicle, payload, and processing worked smoothly. Somehow, despite the absence of lengthy requirements studies, analyses of alternatives, voluminous proposals, large program offices, acquisition approvals, and extensive oversight, this risky experiment was completed in less than 30 months. It was in all respects a "sparkling success."⁷⁸ It generated a wealth of technical data, and it ended with money left over. [REDACTED]

(U) Endnotes

~~(S)~~ Note on sources: This research on Quill

██████████ of the National Reconnaissance Office, commissioned by the former NRO Historian, R. Cargill Hall. Documents and interviews cited in the references are filed in the NRO History Office, unless identified as being held in the NRO Archive Records Center (ARC) or the Army Archive Records Center (AARC).

1. (U) "USAF Pushes Pied Piper Space Vehicle," *Aviation Week* (14 October 1957), p. 26.

2. (U) "Test Firings for Pied Piper Due Soon," *Aviation Week* (16 June 1958), p. 19.

3. (U) In *Aviation Week and Space Technology* 69:10 (8 September 1958), pp. 100-101.

4. ~~(S)~~ The program was directed by Lou Cutrona and others at ERIM (known variously as the Environmental Research Institute in Michigan, Willow Run Laboratories, and the Radar Laboratory of the Institute of Science and Technology of the University of Michigan). This group had demonstrated the first fully focused SAR map in August 1957; its resolution was 15 meters in both range and azimuth. The following June the Army contracted with ERIM to provide developmental SAR models for installing in aircraft. Using five radar systems that Texas Instruments built under contract, ERIM conducted several demonstration flights and delivered the AN/UPD-1 system, consisting of the airborne equipment installed in an Army L-23 (a military model of a Beechcraft V-23), which produced radar data on film, together with a mobile van housing an optical correlator for processing the radar data into useful images. [Cf. Irvin J. Sattinger, *History of ERIM: The Environmental Research Institute of Michigan, 1946-1989* (Ann Arbor, Michigan: ERIM, 1994), p. 39, who reports that there were only four systems.]

5. ~~(S)~~ Radar tantalized aerial navigators through World War II and into the Korean War with the hope of being able to see the ground despite darkness, cloud, or dust, but radar mappers and bombsights of the day never offered sufficient precision. The goal was pursued during the 1950s using two very different technologies. Greater emphasis was given to side-looking radar (SLAR), which concentrated on World War II real-aperture technology and could only find increased precision in larger antennas. Installed in wing pods, under the belly, or along the fuselage, the larger antennas looked to

the side of the flight path and produced a range-delimited silhouette on the radar scope. The scope could be recorded by movie camera and played back to help navigators and pilots become familiar with what they might see on their radar screens during actual operations.

~~(S//TK)~~ The needed precision finally came from a very different approach. During 1951-52 a handful of radar engineers in different organizations thought of using information contained in the phase of radar returns to construct images. Described in the early days as a kind of filtering or Doppler "beam-sharpening" before the term "synthetic aperture" was generally adopted, this approach was pursued most intensively at ██████████ and at the Goodyear Aerospace Corporation.

~~(S)~~ SAR systems point to the side of an aircraft's flight path but they are profoundly different from the real-aperture (SLAR) systems. "With the real array, the return from each range increment is received simultaneously by all array elements every time a pulse is transmitted; whereas, with the synthetic array, the return is collected by the individual elements serially over the period of time the radar takes to traverse the array." [George W. Stimson, *Introduction to Airborne Radar* (El Segundo, California: Hughes Aircraft Company, 1983), p. 528.] Pointing the antenna in a SLAR system, for example, changes the geometry of the scene obtained; in a SAR system it changes the signal-to-noise ratio.

6. ~~(S//TK)~~ Information about Goodyear's research into space-based SARs is drawn largely from an interview with ██████████ the company's project engineer for the Quill radar, 10 May 2001, Litchfield Park, Arizona.

7. ~~(S)~~ The Air Force funded several study teams in this effort. Goodyear and the Glenn L. Martin company were one study team, and Goodyear's ██████████ and ██████████ spent time in Baltimore participating in the study program and writing a proposal to use SAR in the DynaSoar program.

8. ~~(S//TK)~~ Interview with ██████████, 13 June 2001, Chantilly, Virginia.

9. ~~(S//TK)~~ ██████████ thought that Lockheed and Goodyear developed the concept and that Lockheed got King's group interested in it during late fall 1961.

10. (U) Maj. Gen. David D. Bradburn (USAF, ret.), interview, 2-3 May 2000, Los Angeles, California.

11. ~~(S//TK)~~ "Subject is satellite radar experiment," began a 21 November 1962 cable from NRO headquarters to Maj. Gen. Greer, head of the Air Force Special Projects activities on the West Coast. "SAFUS [Charyk] directs the establishment of a separate classified project

under SAFSP management leading toward actual orbital tests and demonstration of the feasibility of radar sensors, including electronic data readout." Secret, ARC Job 199880073 Box 1 Folder 100. Charyk had been briefed on the potential advantages of radar imaging on 18 September 1962 by Captain Gorman, USN ("SAFSP Historical Chronology CY 62," Secret, ARC Job 199800072 Box 3 Folder 11). In December 1962 Charyk told DCI McCone briefly that "Project Quill is research toward an experimental radar payload for bomb damage assessment." Charyk to McCone, memorandum, 14 December 1962, "Memorandum for Mr. McCone," (TS/BYE), ARC Job 199700046 Box 4 Folder 14.

12. (S) The Quill program Office had consisted of three people: Bradburn, [REDACTED], and [REDACTED].

13. (S//FK) Information about the contractual arrangements for Quill is drawn from the Bradburn interview and from Lockheed Aircraft Corporation, *Vehicle 2355 System Report: Volume 1: Summary* (Sunnyvale, California: Lockheed Missile and Space Co., 31 March 1965), pp. 8ff., S/BYE (BIF003/2-195008-80).

14. (S//FK) Lockheed, *Vehicle 2355 System Report 1*, p. 15. The description of mission objectives following in the text is from the same place.

15. (S//FK) Charyk wrote to DCI John McCone that "Project QUILL is research toward an experimental radar payload for bomb damage assessment" (Joseph V. Charyk, Director, National Reconnaissance Office, to Mr. McCone, memorandum, 14 December 1962, p. 4, TS/BYE, ARC Job 199700046 Box 4 Folder 14). Officers from Program A had been discussing the Strategic Air Command's need for reconnaissance data to assess bomb damage inflicted by nuclear strikes. A year later, the new director of the NRO, Brockway McMillan, told the United States Intelligence Board and the 5412 Group that "the Quill experiment is being conducted to demonstrate the feasibility of high resolution radar for terrain reconnaissance from a satellite," and that it was expected to achieve "about a 100-foot resolution over a swath width of 10 miles" ("Status of Satellite Reconnaissance Programs," 13 November 1963, p. 7, TS/BYE, ARC Job 199700046 Box 4 Folder 14). A Program A staff paper prepared during summer 1963 (but not released) reported that "20 ft. resolution is the very best we can expect from present know-how and resolutions of 40-50 feet are more likely. 20-50 feet resolution is considered adequate for the Post Strike Assessment mission where all we need to know is where the bomb hit, but whether a radar PSA system is practical as an operational system remains to be seen. . . . Further effort in this field should be held up until we are able to get some answers from the Q [Quill] tests. Only then can we assess the future capa-

bilities of radar in satellite reconnaissance and only then can we know the feasibility of a practical operational PSA satellite" (Colonel [REDACTED] "Satellite Reconnaissance," July 1963, p. 20, TS/BYE, ARC Job 199700046 Box 46 Folder 14).

16. (S) Bradburn's approach to managing the project evidently embodied the precepts of the "King Doctrine," attributed to Bill King when he was head of [REDACTED]. They admonished managers to keep the program office small, hand-pick their people, control contractors by direct personal contact, stress that program success is the *raison d'être* for the program office, and "keep it simple." The latter meant using proven components whenever possible, trimming non-essential engineering, buying fewer spares, sticking to a single checkout, abbreviating documentation, and simplifying tests. Briefing attached to note from J. C. Fitzpatrick, annotated "given 28 Sept 1989 at LA," in file, "Jim Fitzpatrick 19 Jun 90," Bradburn papers on sigint history study, unaccessioned, NRO History Office files. In Perry's view, Bradburn "emphasized those qualities of incrementalism and low-risk technology espoused by King, [Col. C. Lee] Battle, [Col. Paul E.] Worthman, and Greer," and the project itself "seemed another proof of the validity of a policy of incremental acquisition." Robert L. Perry, "Recce Satellite R&D: Capabilities in Readout, Crisis Reconnaissance and Very High Resolution," final draft of Chapter XVII in his *NRO History*, pp. 10-11, S/BYE in ARC Job 199600096 Box 6 Folder 10.

17. (S//FK) [REDACTED] August 1965), pp. 115-117, SECRET-SPECIAL HANDLING.

18. (S//FK) Information about the payload is drawn from Goodyear Aerospace Corporation, *Engineering Analysis Report No. 1, KP-II Radar System* (Litchfield Park, Arizona: Goodyear Aerospace Corporation, 25 July 1964), SECRET-SPECIAL HANDLING.

19. (S//FK) [REDACTED] *Evaluation I*, p. 5.

20. (U) Bradburn, interview.

21. (S//FK) Lockheed, *System Report 2*, p. 1-139.

22. (S//FK) Lockheed, *System Report 2*, pp. 1-133-1-154.

23. (S//FK) [REDACTED] *Evaluation II*, pp. 251ff.

24. (S) "In its recent annual report, Lockheed referred to a statement by Maj. Gen. Bernard A. Schriever, commander of Air Research and Development Command's Ballistic Missile Division, that the reconnaissance satellite system will include a recoverable capsule." "Test Firings," *Aviation Week* (16 June 1958), p. 20.

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25. (S//FK) Goodyear, *Engineering Analysis*, p. 9-1.
26. (S//FK) "A light source is collimated by lens L_c to illuminate the film with a coherent wave of light. The lenses L_1 and L_2 are set as a telescope and have the primary purpose of imaging the tilted recording plane. The three cylindrical optical elements are also telescopic and, in conjunction with the spherical telescope, image the tilted azimuth plane so that it is coincident with the imaged range plane at the recording surface. A three-element cylindrical telescope is used so that the azimuth magnification of the optical system can be continuously adjusted. This allows the processor to easily accommodate various azimuth scale factors. The filter plane aperture, between the two spherical lenses, serves the purpose of removing two of the three waves formed in the diffraction process, as only one of the waves (either the convergent or divergent) is necessary to make the fine-resolution map." [REDACTED] *Evaluation II*, pp. 259-260.
27. (S//FK) Goodyear, *Engineering Analysis*, pp. 4-1-4-12.
28. (U//FOUO) Col. Jack Ledford, to Deputy Director (Research), memorandum, S/BYE (BYE-2453-63); AARC Job 80B00251A Box 1 Folder 3. Scoville did not long remain as deputy director for research; he had been frustrated for months in his attempts to create the research organization by acquiring elements of other CIA organizations, and in June 1963 he resigned. Director McCone chose Albert D. "Bud" Wheelon to replace him.
29. (S//FK) As of 24 July 1963 SAFSP estimated that the support would cost [REDACTED] (cable dated 1643Z 24 Jul 63, S/BYE, AARC Job 80B00251A Box 1 Folder 65). This cable also identified May 1964 as the intended launch date, and identified September 1964 as the date for having a second ready (payload only). The following month (August 1963) OSA estimated that its support to Quill would cost [REDACTED] see memorandum dated 21 August 1963 from [REDACTED] concerning FY64 status of black funds, SECRET-SPECIAL HANDLING, AARC Job 80B00251A Box 1 Folder 65. Contractor requirements at that time were identified as [REDACTED] leaving a balance of [REDACTED] in the CIA's Quill account.
30. (S//FK) Bradburn to [REDACTED] and [REDACTED], "Security Plan—Action Items," memorandum, 19 December 1963, S-Special Handling, and enclosure 1, "Quill Supplement, Covert Programs Security Plan," 2 March 1964, S-Special Handling.
31. (S//FK) Cable dated 26 Mar 63 2334Z from [REDACTED] to OSA [REDACTED], SECRET, AARC Job 80B00251A Box 1 Folder 3.
32. (U//FOUO) SAFSP Director, *Quarterly Report*, 31 May 1964, TS/BYE.
33. (U//FOUO) SAFSP Director, *Quarterly Report*, 31 May 1964.
34. (U//FOUO) SAFSP Director, *Quarterly Report*, 30 September 1964, TS/BYE.
35. (U//FOUO) SAFSP Director, *Quarterly Report*, 30 December 1964, TS/BYE.
36. (S//FK) Cf. the *Quarterly Report* for 30 December 1964: "the batteries were depleted by Rev 79, which agrees with predicted battery life." Subsequent testing on the KP-II indicated that the mission would not have lasted much longer in any event. Small potting voids in two high-voltage modules grew in size with repeated temperature cycling and provided a high-voltage corona discharge path that eventually led to catastrophic failure. Once identified, the problem was readily addressed and the corrective action proven with an extended life test. See Goodyear Aerospace Corporation, *KP-II Final Report: Experimental Laboratory Investigations BKP-II-16* (Litchfield Park, Arizona: Goodyear Aerospace Corporation, 31 March 1966), pp. 5-6, SECRET-SPECIAL HANDLING.
37. (S//FK) Such a limit had been contended in some contemporary technical papers, including some from the Aerospace Corporation, according to [REDACTED] (interview).
38. (U//FOUO) SAFSP Director, *Quarterly Report*, 30 December 1964.
39. (S//FK) Lockheed, *System Report 1*, pp. 37-38.
40. (S//FK) Secondary objectives are described in Lockheed, *System Report 1*, pp. 15-17; and [REDACTED] pp. 3-4.
41. (S//FK) [REDACTED], interview.
42. (S//FK) Lockheed, *System Report 2*, pp. 4-14-4-15.
43. (S//FK) "Two independent measures of achieved resolution are available. The first of these is obtained from the imagery of Pass No. 8 itself—a test array of radar corner reflectors at [REDACTED] [REDACTED] fell within the mapped swath. The image of this array showed that azimuth resolution of roughly 10 feet, and ground-range resolution of roughly 75 feet, were achieved. The second determination was made via a measurement of the two-dimensional response of the system to a strong isolated target which was imaged near the southern end of Pass 30. The system impulse response determined directly at the output of the optical processor, had a half-power width of 10 feet in

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azimuth and 72 feet in ground range." Lockheed, *System Report 1*, pp. 34-35.

44. (S//FK) "The usable imagery obtained represents 88,000 square miles or 79 percent of the illuminated terrain; of the total, 63 percent is substantially as good as the system was designed to produce, while 16 percent suffered only from uneven illumination caused by slightly incorrect pulse repetition frequency (prf) setting. Another 17 percent of the attempted coverage was sacrificed during various test sequences in which the prf and/or the attenuation level were intentionally mis-set. Of the 4 percent that was unintentionally lost, the major portion was the victim of occasional failures of the ground-recorder to resynchronize its sweep promptly when prf was switched, during those times when the system was dependent on the data-link output. An easily correctible fogging of the onboard film between active passes also accounts for some loss of imagery." ██████ *Evaluation 1*, p. 15.

45. (S//FK) Lockheed, *System Report 1*, p. 146.

46. (S//FK) ██████ p. 89.

47. (S//FK) Lockheed, *System Report 1*, p. 146.

48. (S//FK) ██████ pp. 91-92.

49. (S//FK) Lockheed, *System Report 1*, pp. 146-148.

50. (S//FK) Goodyear, *KP-II Final Report*, pp. 151-154.

51. (S//FK) ██████ interview.

52. (S//FK) Greer's cable is ██████ 7061 11 Feb 65, subject: Disposition of Quill Hardware (ARC Job 199800073 Box 1 Folder 106). In ██████ 2456 15 Feb 65 NRO headquarters approved placing the remaining Quill hardware in storage pending receipt of the report of the evaluation committee in Washington.

53. (U//FOUO) SAFSP Director, *Quarterly Report*, 30 June 1965, TS/BYE.

54. (U//FOUO) SAFSP Director, *Quarterly Report*, 30 June 1966, TS/BYE.

55. (U//FOUO) Memorandum for the Record, "List of Topics for Discussion with ExCom," TS/BYE (BYE 12941/69), 13 June 1969, in ARC Job 199700046 Box 4 Folder 8.

56. (S) "NRO Position Paper on the NRO Satellite Radar Program," attachment to John L. McLucas to Assistant Secretary of Defense (Intelligence) and Director, Defense Research and Engineering, memorandum, "Synthetic Aperture Radar Surveillance Satellite System," 10 October 1972, TS/BYE (BYE-13130-72), in ARC Job 199900005 Box 2 Folder 19.

57. (S//FK) ██████ interview.

58. (S) Bradburn had been promoted to Lieutenant Colonel by the time of the launch, and in the summer of 1965 left Los Angeles to attend the Air War College. He planned his next tour to be in Washington, D.C., but returned to Program A at the request of Brig. Gen. King. In June 1966 SP was planning to transfer the Quill project from the sigint office to the advanced technology office, headed by then-Colonel Lew Allen, Jr. Bradburn was promoted to Colonel during his year at the War College and returned to SP to head the sigint office, ██████ Bradburn, interview.

59. (U//FOUO) SAFSP Director, *Quarterly Report*, 30 June 1966.

60. (U//FOUO) SAFSP Director, *Quarterly Report*, 30 September 1966, TS/BYE.

61. (U) Bradburn, interview.

62. (U//FOUO) Brig. Gen. John L. Martin, USAF, to Director, NRO (Dr. Flax), memorandum, "Survey and Audit of Cost Reduction Items," S/BYE (BYE-66289-66), in ARC Job 199800073 Box 1 Folder 125.

63. (U//FOUO) Charyk to Greer, 21 November 1962.

64. (S//FK) "We greatly appreciate your offer of SAC assistance in evaluating the Quill system; specifically, its application to the BDA [bomb damage assessment] problem." Brig. Gen. James T. Stewart, director, NRO staff, to Maj. Gen. Robert N. Smith, director, intelligence headquarters, SAC, memorandum, "Evaluation of Radar Imagery," 9 February 1965, TS/BYE (ARC Job 199800073 Box 1 Folder 106).

65. (S) Col. ██████ USAF (ret.), interview, January 2000, Waterton, Colorado.

66. (U//FOUO) SAFSP Director, *Quarterly Report*, 30 June 1966.

67. (S) An imaging radar satellite, even with better resolution than Quill, might in fact have been irrelevant to SAC's operations. At the time, the declared nuclear strategy of the United States was an oxymoron, emphasizing both "damage limitation" and "assured destruction." Damage limitation called for building offensive forces that could destroy enemy offensive forces and so, together with antiballistic missiles and civil defense, make it more difficult for Soviet forces to damage the United States. Soviet leaders were presumed to see from these forces that they would not be able to achieve any reasonable war aims and so would be deterred from striking the United States first. Assured destruction, on the other hand, argued that deterrence was based more safely on the assured ability to punish a Soviet first strike by destroying Soviet cities and industries in significant amounts; Soviet leaders were presumed to see that by attacking the United States first they would lose far more

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than they could hope to gain and so would be deterred from doing so. The contradiction between these themes arose because efforts to improve a damage limitation capability undercut the assured destruction philosophy, as John Newhouse explained, "because it may degrade your adversary's ability to destroy your own cities in a second strike. His confidence undermined, he might then be tempted in a crisis to strike pre-emptively; in short, knowing you are effectively protected from his second-strike assault and fearing your intentions, he may choose to strike first." John Newhouse, *Cold Dawn: The Story of SALT* (New York: Holt, Rinehart, and Winston, 1973), pp. 9-10. Secretary of Defense Robert S. McNamara argued for the primacy of damage limitation in 1962 ("the principle [sic] military objective in the event of nuclear war should be the destruction of the enemy's forces [not his population]," and for assured destruction in 1967 ("I think we could all agree that if they struck first we are going to target our weapons against their society and destroy 120 million of them." Newhouse, *Cold Dawn*, p. 11).

68. (U//FOUO) Dr. Alexander Flax, interview, 5 February 2003, Chantilly, Virginia.

69. (U//FOUO) Draft manuscript, "Satellite Reconnaissance," marked "Colonel [REDACTED] Study, Not Released," July 1963, TS/BYE, pp. 20-21, ARC Job 199700046 Box 4 Folder 14.

70. (U//FOUO) Office of the Historian, National Reconnaissance Office, "Former NRO Directors Series: Interview with Dr. Alexander Flax," 22 May 1997, LIB # 01881, S/BYE.

71. (U//FOUO) Dr. Alexander Flax, interview, 21 November 2002, Potomac, Maryland.

72. (S) "Proposing the radar satellite just seemed so obvious. You could go to where they had the film [NPIC] and see lots and lots of clouds, week after week, nothing but clouds, and we needed timely information." John S. Foster, Jr., interview, 4 December 2002, Washington,

D.C. In his budget review in November 1966, Foster wrote that funding for "direct read-out" for imagery should be reduced and "emphasis placed on an all weather capability and in advanced development for overhead sigint." Foster to Flax, memorandum, 22 November 1966, "Special Support Activities RDT&E FY 1968 Budget," TS/BYE (BYE-5662-66; ARC Job 199800073 Box 1 Folder 118).

73. (U//FOUO) Perry, *Management*, pp. 106ff.

74. (S//FK) McMillan was less careful and cost himself technical credibility. He rejected the development of

[REDACTED]

[REDACTED] He concluded fantastically that the NRO would instead accomplish the intercepts by building "a covert, and relatively inexpensive, element of a satellite openly developed for other purposes, purposes which in themselves come close to justifying the costs involved." Such purposes, he went on to say, might be weather observation or communication relay. McMillan to deputy director, science and technology, CIA, memorandum, "Studies of Synchronous Satellites," 5 November 1964, TS/BYE (BYE-23486-49), ARC Job 199800066 Box 3 Folder 2.

75. (S//FK) [REDACTED]

[REDACTED]

76. (S//FK) Information in this paragraph was provided in part by [REDACTED] interviews, 17 March 2000, [REDACTED]

77. (S//FK) [REDACTED] interview.

78. (U//FOUO) Perry, "Recce Satellite R&D," p. 11.

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