~~(S)~~ QUILL

~~(S)~~ Radar In Orbit

Robert L. Perry

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(U) Introduction

~~(S//TK)~~ This comprehensive history of the first radar imaging satellite describes the program's evolution from need to concept to program to launch and evaluation while stressing its experimental nature: "the feasibility system was to be that and nothing more; no consideration would be given to making the demonstration equipment the basis of an operational system." Robert L. Perry's Quill history bring interesting contractual, administrative, and financial minutiae as well as technical details. He provides a vivid sense of Bradburn's management style as well as the Cold War setting of the time.

(U) *Robert L. Perry* (May 10, 1925-September 7, 1990) majored in journalism at Marshall University, graduating in 1947. He went on to a master's degree in history at The Ohio State University. From 1951 to 1964, Bob Perry worked for the Air Force—first at Wright-Patterson Air Force Base, Ohio, then as chief of the History Office at Air Force Systems Command, El Segundo. He was a retired USAF reserve officer who also taught or lecture at Ohio State, Wittenberg University, the University of Dayton, the Air Force Academy, the Air University, California Institute of Technology, and the Rand Graduate Institute. He also wrote extensively on Air Force system development programs, chiefly aircraft and missiles. In October 1964 Bob Perry joined the Economics Department of the Rand Corporation, where his list of publications includes more than 25 technological case histories, studies of R&D policy, analyses of system cost trends, examinations of test program structures, and comparisons of U.S. and foreign technologies and R&D institutions. He also served on numerous outside panels and gave testimony to several congressional committees.

XVI QUILL: RADAR IN ORBIT

In the first 20 years of reconnaissance satellite program activity in the United States, Quill was the only program that substantially conformed to initial cost, schedule, and performance estimates, and the only satellite program of any nature to proceed from start to finish with a perfect record in launch, orbital operations, readout, and recovery.

Quill had its immediate origin in a proposal jointly concocted by Lockheed Missiles and Space Company and the Goodyear Aerospace Corporation early in 1962. Stimulated by rising interest in post-strike reconnaissance capabilities, those contractors suggested that a synthetic aperture side-looking radar be installed in an Agena spacecraft for assessment of weapons effects in a post-nuclear-strike setting. The radar set was to be a modified version of one being built for the RF-110 (which subsequently reverted to its original RF-4 nomenclature). A Lockheed briefing team that included Goodyear representatives exposed the notion to a variety of interested audiences in the middle months of 1962. Air Force Undersecretary Joseph V. Charyk, who also headed the still-secret National Reconnaissance Office, was one of those who listened. Major General Robert E. Greer's Directorate of Special Projects (the West Coast element of the NRO) provided another audience.

The idea of using orbiting radar for bomb damage assessment was scarcely novel in 1962. It had first been mentioned as part of Rand's initial studies of satellite feasibility and applications between 1948 and 1952, and had reappeared periodically during the next decade. Strategic Air Command interest in satellite-based, post-strike reconnaissance, pronounced for several years, was heightened by the 1961-1962 cancellation of the original photo-readout Samos satellite programs (E-1 and E-2), which until that time had been somewhat unrealistically counted on to provide retargeting data. In 1960 there was a brief flurry of interest in the idea of a combination bomb-damage-assessment and weather reconnaissance radar satellite, but like other ambitious proposals of the time it expired of funds starvation and technology shortcomings. Nevertheless, such discussions encouraged Lockheed to propose the near-term development of a radar-carrying reconnaissance satellite that used on-the-shelf components.[1*]

* Source citations are to be found at the end of each chapter.

Greer, with Charyk's support, asked his Plans Chief, Captain Frank Gorman (USN) to examine capabilities and needs. Concurrently, Colonel [redacted] of Greer's staff established a working relationship with the Strategic Air Command's requirements group in the hope of clarifying SAC's post-strike reconnaissance requirements. [redacted] learned little that was new: SAC wanted a satellite-borne, post-strike, all-weather assessment capability in near-real-time. Gorman, after surveying the entire spectrum of requirements and capabilities, reached the initial conclusion that any system ". . . requiring reflected light cannot be considered a good solution to a problem where reaction time is paramount as is the situation for 'initial assessment.'" In Gorman's judgement, the only effective technique would be one providing "all weather/light conditions" sensitivity. His recommendation to Greer: "A high-resolution radar development should be initiated immediately if an effective post-strike reconnaissance capability is to exist." And he concluded that readout was essential; physical recovery of payloads, he argued, had been "a means of circumventing the bandwidth problem."[2] All of which was true, but in the absence of adaptable technology, was also largely irrelevant.

Nevertheless, the several elements necessary to the establishment of a funded research and development effort that could lead by one route or another to an operational radar-in-orbit system were in being by the late summer of 1962. A requirement of sorts had been acknowledged, though no formal statement of national need for radar reconnaissance from orbit had yet emerged. The approach defined by Lockheed and Goodyear,* if it could be accepted at face value, represented a technologically achievable capability that could be acquired at a relatively modest cost. The ingredients of a system existed in the form of in-development items if not in operationally ready equipment.

In June 1962, Charyk directed that Greer's organization evaluate the possibility of adding special sensors "such as infra-red and radar" to the payload of the heavy-lift Titan-III vehicle then being considered as a successor to the Atlas booster used for most space launches. The slight prospect that the Titan-III would actually be used in the satellite reconnaissance program for several years prompted Greer to suggest consideration of a more direct approach. In October Charyk accepted Greer's views and formally authorized an evaluation of the

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* Other contractors had similar proposals, but all required some extended period of vehicle or sensor development.

Lockheed-Goodyear proposal based on use of a Thor booster and readily available Agena hardware.[3]

What began in the summer of 1962 as an evaluation became a source selection process. It had two aspects, one involving a normal competition for the development of a radar set, boosters, readout equipment suited to extended operations, and the other an experiment using the Lockheed-Goodyear proposal as its base. Major David D. Bradburn, a member of the six-man study group,* suggested that the most direct and effective way of satisfying Charyk's request for an early demonstration of radar-in-orbit feasibility was to buy a few sets of on-the-shelf equipment, modify the hardware sufficiently to permit its operation under orbital conditions, and test the result in a real operation. The group's head, Colonel William G. King, Jr., was wholly in favor of that approach but having recent and painful experience with optimistic contractor predictions that could not be translated

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* The study group, headed by Colonel W. G. King, Jr., included Lieutenant Colonels John Copley and [redacted]. Major Bradburn, Major Charles Redwine, and Captain [redacted], all of Greer's staff. Three "advisors" also signed the final report, Lieutenant Colonel [redacted] who was Greer's legal specialist, Lieutenant Colonel Victor M. Genez of the SP Plans staff, and [redacted].

into operational performance,* decided to verify the alleged performance capabilities of the proposed system by checking with Air Force radar reconnaissance experts at Wright Field.

The entire six-man study team visited the Reconnaissance Laboratory, an element of the Aeronautical Systems Division at Wright-Patterson Air Force Base, early in October. The project officer for the AN/APS-73 radar, [redacted] assured his visitors that the set could do what had been promised for it and that no other item of available equipment could realistically be substituted. The question of what resolution could be expected was not as readily resolvable. Colonel [redacted], the Laboratory's chief, told Colonel King that if suitable "requirements" could be issued it would be possible to obtain comparison radar and photographic imagery of existing bomb craters at Frenchman's Flats (the Nevada test site) in four to six months. King, who planned to write his final report later that month, said mildly that he had a better idea. One of his team members who knew the problem intimately was Captain [redacted] King said. Captain [redacted] could adequately represent the

* King had managed the Samos E-1 and E-2 programs, had been involved with satellite reconnaissance work since 1955, and was the final program manager for the wholly inadequate Snark missile.

study group in superintending an immediate effort, say in three or four days. He would fly aboard the photo airplane.

[redacted] after a moment's reflection, agreed that the test exercise could indeed be completed in three or four days. It was, and comparison photographs were being examined in Los Angeles the following week. They demonstrated that radar imagery could readily distinguish the principal features of bomb craters of various kinds, although the limitations of the test photography excluded any firm conclusions about the ground resolution obtainable from space by side-looking radar. "However," King's group eventually concluded, "it is obvious that craters and surface differences of the sizes identified in the accompanying photographs can easily be seen with a radar that has a ground resolution poorer than 50 feet."*

* The craters photographed ranged in diameter from a minimum of 80 feet to a maximum of 850 feet. Photographs were taken using a six-inch focal length T-11 aerial camera loaded with Plux-X film, the combination providing a 20-lines-per-millimeter resolution at the film plane. The radar was an AN/APQ-55, with a six-foot, slotted-roll, side-looking antenna, 45 kilowatts of power, and a frequency of 34.86 kilomegacycles. An electro-optical photo multiplier tube, an indium antimony infrared detector, and the radar operated as part of a development system being investigated by the Reconnaissance Laboratory. They were flown 2200 feet above the craters in a C-131 aircraft.

Having confirmed their preliminary judgement that radar in orbit could adequately perform bomb damage assessment (if it could be made to operate while in space), the study group had to confront the question of what to recommend to General Greer and ultimately to Undersecretary Charyk. Several contractors had provided copies of earlier unsolicited proposals and had briefed group members. In the end the study group settled on a recommended approach which was characterized as ". . . not . . . the only feasible or best concept; . . . [but] merely . . . one concept having some plausibility--a basis from which the Board may proceed." The members were agreed that they would have satisfied the requirements of their charter if they provided (a) a conceptual foundation and operative recommendations for proceeding with a radar feasibility demonstration, and (b) guidance for the conduct of further studies and analyses.

The final report said candidly, "we have assumed that our instructions limit us to showing the feasibility of developing a satellite-borne radar capable of sensing information of sufficient intelligence value to allow some damage assessment. The more subtle problem of showing the feasibility of an overall post strike reconnaissance system must be fully analyzed concurrently with any radar demonstration."

The study program was intended to analyze the operational applications of high-resolution radar for bomb damage assessment in a post strike environment, assuming quick-reaction, all-weather capability for acquiring "the relatively coarse detail" obtainable from satellite-carried radar.*

The feasibility demonstration was seen as a process that should be conducted quickly and with the minimum outlay of funds needed to assure success. Following the lines of Bradburn's suggestion the group urged testing off-the-shelf radar ". . . capable of providing information which can be extrapolated (at minimum risk) into design information required for an operational radar . . ." The object of the demonstration would be to establish that ". . . physical phenomena do not exist which would preclude development of high resolution."

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* Although the study group report did not explicitly so state, group members were convinced that the analysis should be performed outside the Special Projects directorate, preferably by the Strategic Air Command. The participation of Rand Corporation specialists was explicitly proposed, however. In the event, the "studies and analysis" aspect of the total Quill program did not develop as the study group had proposed. Charyk never directed Greer's organization to do the analysis. Rand did perform some relevant research, but SAC continued to submit advocacy recommendations which, generally, were considered by senior defense officials to be insufficiently supported by objective analysis. The feasibility demonstration aspect of Quill became, by a process of inaction elsewhere, the dominant element of the program.

To those ends, the study group recommended that an APS-73 model radar be integrated with a Thor booster, an Agena-D orbiting vehicle, a Corona recovery capsule, a readout system chosen from existing hardware,* an available ground processor, and the orbital control and communications net then being used by the National Reconnaissance Program. It was a somewhat less ambitious variant of the Lockheed-Goodyear approach, but devoid of operational objectives.

Concluding that only the equipment combination proposed by Lockheed and Goodyear could be made available for a timely demonstration, the study group recommended an immediate start of work using a sole-source procure-

* Relatively little was said about readout in the final report, which, however, included a general discussion of principles and techniques and an assessment of readout time requirements. As for feasibility, something of the group's views could be judged from the provision of a recovery capsule, an accessory that presumably would not find a place in any operational system. A brief but eloquent comment on the readout problem appeared toward the middle of the report: "Airborne and ground equipments to provide bandwidths of six megacycles have been developed, tested, and shown to be technically feasible. Their reliability leaves something to be desired." And, after a discussion which ended with the observation, "Our problem is not in sensing in detail, but . . . is retrieval of the information," the report suggested the "broad assumption" that ". . . information of a modest detail level which can be handled may be useful for an 'initial assessment.'" (Underlining in the original text.)

ment approach.* The evaluation group concluded that a three-flight demonstration effort could be conducted at a cost of [redacted], but that a ten-percent contingency fee should be provided to protect against unforeseen development problems. (Should a five-flight program be approved, required funds would total [redacted])

Finally, the group recommended that the existing [redacted] house the feasibility demonstration, and that Major Bradburn, "probably the most knowledgeable radar specialist at SAFSP," be named

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* That somewhat unusual course--selecting contractors during an evaluation of program feasibility--was justified by Charyk's requirement for the quickest possible demonstration, which meant use of off-the-shelf equipment. The Agena-D was the only available orbital vehicle, the Thor the only appropriate booster previously mated to an Agena, and the APS-73 was "the nearest thing to an off-the-shelf item that could be used in the feasibility demonstration . . ." In the formal opinion of Colonel [redacted] because only Goodyear made that radar ". . . it would be a gross waste of time and money to start another manufacturer building it in lieu of having Goodyear make the necessary minimum modifications in its existing product."[4]

program manager.* In a statement that Bradburn was to emphasize frequently thereafter, the group observed that the orbital test program was ". . . the simplest and quickest approach to demonstrating the feasibility of the radar sensor," that quick completion of the test would make possible a decision on a later operational system, but that ". . . the launch vehicle and radar configuration proposed for orbital test are not considered adaptable for operational test." In so many words, the feasibility demonstration was to be that and nothing more; no consideration would be given to making the demonstration equipment the basis of an operational system.**

* Quill, which promised to be a short-term program of high technical interest, would be an attractive project to manage. Bradburn told King he was bored with his current assignment and asked, "Why don't you make me the project officer reporting to you? Then I'll be able to do it quickly and cheaply and you can protect me from all the colonels who might want the job." King thought well of the idea.
of the idea.

** A post strike bomb damage assessment system, as conceived then and later, was assumed to involve requirements for multiple launches from hardened sites. The use of a Minuteman booster was generally believed to be a prerequisite for operational utility, that being the principal land-based ballistic missile in the U.S. inventory. The October 1962 study postulated five near-simultaneous launches, with five orbital radar systems making parallel-path passes over the principal Soviet targets. Obviously, a soft, liquid-fuel Thor was wholly inappropriate for such an operation, Agena could not be accommodated in a Minuteman silo, and the APS-73 radar promised to have definition and resolution inappropriate for an operational application.

The report of the study group, thereafter known as the "King Report," went to General Greer on 30 October. Its one-word title, "Quill," became the program's code name.[5]*

Greer approved the findings and recommended that Major Bradburn, the board's nominee for project leader, present them to Charyk for review. Three days after Bradburn's 7 November 1962 presentation, Charyk authorized him to begin work. Funding levels, as first approved, reflected the premises of the Lockheed-Goodyear proposal. Bradburn's plans called for five flight-qualified payloads, of which three were actually to be launched. Lockheed was to be assigned system engineering and technical direction responsibilities and responsibility for orbital vehicles, system integration and launch services. Goodyear Aircraft was to develop the radar payloads.**

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* Quill was suggested by Colonel Joseph W. Ruebel. At West Point, the term "Quill List" was used to identify the weekly listing of cadet demerits--the discipline list. To be "on Quill" was, therefore, a highly undesirable assignment. That was not the way the eventual Quill participants viewed their assignment, of course.

** Lockheed was to perform system integration, engineering and fabrication of structural modification for three orbital vehicles, antenna design and fabrication, provide special batteries and other payload-peculiar vehicle equipment; and do test planning, in-plans and launch-base checkout services. Goodyear was to be responsible for engineering, fabrication, qualification and delivery of five flight-qualified satellite radars, one qualification test radar substantially identical to a flight article, one thermal equivalent test model, one mock-up, air-to-ground equipment for checkout at Goodyear and for system checks at Lockheed, and pad checkout equipment at Vandenberg AFB, including test beacons and apparatus for blockhouse checks of radar operation during countdown.

[redacted] had agreed to provide engineering consulting services for the radar experiment and to develop an optical correlator for final processing of radar data. General Electric Company was to build the reentry vehicle and Douglas Aircraft the thrust-augmented Thor boosters. The project goals included physical recovery and electronic data readout at a ground resolution of 100 feet or better. Real-time electronic readout over one United States station would be acceptable. The project--white name "P-40"--was to operate with a minimum of modification to all off-the-shelf systems, including the Goodyear radar, and was to be concluded as rapidly as possible. Time on orbit and data quantities were not considered critical items. However, Charyk wanted to be informed immediately if there were any question of meeting the 100-foot resolution requirement. He also insisted that contractors be clearly informed that the demonstration was of an experimental nature only and was not a device for acquiring operational radars or for starting the development of an operational system.

As Greer had suggested, Charyk directed that the demonstration project be conducted under a "black" cover. He authorized the notification of chosen contractors and the release of [redacted] in fiscal 1963 funds to cover initial costs. An additional [redacted] would be provided for fiscal 1964.

Charyk also approved the conduct of more refined experimental work in advanced radar techniques. Designated "Phase Alpha," that aspect of the total project was to be separately classified "white" but with strict "need to know" security. Under Special Projects Office auspices, competitive proposals were to be issued asking for design studies looking toward orbital tests and demonstration of the feasibility of radar sensors with electronic readout and storage capabilities (recovery was not an excluded option, however). Acceptable ground resolution was to be specified at 20 to 50 feet. All concerned expected Phase Alpha to take longer than the P-40 demonstration. 6

On 14 November 1962, Bradburn advised the selected contractors that the Air Force proposed to accept their unsolicited proposal to test a radar satellite. Bradburn and others from Special Projects the directorate met with Lockheed, Goodyear and [redacted]* representatives at Sunnyvale. [redacted] from Lockheed had been asked to be ready to present again the proposal he had earlier made to King's group and to bring cognizant Goodyear people with him.

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* Attendees included Colonel Robert W. Yundt, who had succeeded W. G. King as Bradburn's immediate superior for <u>Quill</u>.

Bradburn informed the contractors that the Air Force was going to proceed with a minimum satellite radar demonstration, generally along the lines of the Lockheed-Goodyear proposal, but on an associate-contractor basis. Although Lockheed had favored a primary contractor-subcontractor framework, the Air Force had decided that direct access to the major contractors involved would limit schedule and cost overruns and thereby enhance the probability of an early first flight. Lockheed, Goodyear and [redacted] would all have direct communication lines to Bradburn. Bradburn explained that he wanted to exploit existing contracts as much as possible, not only for administrative ease but also for purposes of maintaining security.

The project framework, as laid out by Bradburn, included procurement of five flight-qualified payloads to support three flights at two-month intervals with the first flight targeted for January 1964. The goal would be to obtain a high-resolution radar picture from a satellite (ground resolution of 100 feet or better) in minimum time and with minimum modification of existing hardware.

[redacted] (Aerophysics Division of Goodyear) briefed the meeting on the radar system then being developed by Goodyear for the RF-110 aircraft. Capable of producing 50-foot ground resolution, the basic radar covered two 30-mile swaths, one on either side of the airplane. The inflight recorder and display equipment permitted display of two ten-mile swaths which could be selected as desired within the coverage limits. The all-up weight of the radar was 450 pounds (including antenna, recorder, transmitter and receiver).

[redacted] foresaw the need for three principal changes to adapt the existing APS-73 radar for satellite use. The pulse repetition frequency (prf) and the average power would have to be increased, the transmitter/modulator (and perhaps other components) which used refrigeration cooling would have to be repackaged to provide for conduction or radiation cooling, and the recorder would have to be modified to accommodate a large film supply and to provide for satellite-derived data inputs.

Existing development schedules called for initial bench testing of the first complete RF-110 radar in April 1963 and delivery of the first flight test item to Edwards Air Force Base in July. However, there was already some indication of slippage and [redacted] cautioned that flight tests might not begin until September or October.

[redacted]

[redacted] described the operating principles of the optical correlator. [redacted] could achieve an azimuth compression ratio of 1000 to 1 with available production-type processors. (The azimuth resolution in the final picture would be 1000 times finer than the physical dimensions of beam width.) With laboratory-type demonstration equipment, the best obtainable azimuth compression ratio was about 5000 to 1. In the proposed satellite experiment, azimuth resolution would be limited primarily by ionospheric distortions. If all worked well, the overall system might produce azimuth resolution of 15 feet or better. At any rate, the optical processor would not be the limiting factor.

During the engineering discussions that afternoon, Bradburn specified that the payload configurations would be identical from flight to flight--there would be no growth changes. He emphasized the "minimum modification, as-short-a-time-span-as-possible" philosophy which was to guide Quill. He also restated his determination to adhere closely to the primary goal of showing feasibility, not developing operational prototypes. One consequence was that the radar antenna would not be steerable. Concerned with acquiring a good picture at acceptable ground resolution and not with viewing specific targets, Bradburn foresaw no need to develop aiming capability; the swath would be wholly dependent on the orbital path of the vehicle.

Although recovery of the exposed film would be the primary data retrieval method, simultaneous readout of the radar data would provide a comparison in picture quality and reveal what data deterioration was caused by the transmission link. Readout would also provide a backup system in case the recovery system failed.

Lockheed agreed to provide within 24 hours an initial cost figure so funds could be added at once to an on-going Air Force contract [redacted]. A work statement was to be ready by 21 November and a full cost proposal within the month. Contract negotiations, to begin in January 1963, were scheduled to lead to a definitive contract by 25 January 1963. Bradburn scheduled a meeting with Goodyear for the week of 18 November, in Phoenix, to discuss a draft work statement, proposed contract arrangements, and procurement schedules. Meetings with the [redacted] were set for early December.*

* The principal contractors were in a state of financial near-shock when Bradburn told them that Greer's organization had accepted their premises and promises and proposed to proceed with the program

Bradburn emphasized the need for tight security. Each employee working on the project would have to be approved by the Air Force, sign a security agreement, and have a final secret clearance. Bradburn requested that he approve these names in advance, an arrangement he later changed to allow for after-the-fact notification to the limits of a quota for each company.

Bradburn also stressed the need to hold documentation to a minimum, both for security reasons and to lessen paperwork. Each company would deal directly with his office, so a multiplicity of reports would be a waste of time as well as a potential security risk. He emphasized that he intended to participate in most of the monthly engineering and technical review meetings and that he expected all program participants to use them as a primary means of informing all concerned parties of technical, cost and scheduling
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detailsling matters.

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*(continued) pretty much as they had briefed it--and at about the price they had proposed. As later became plain, and as everyone concerned privately acknowledged at the start, the financial estimates originally attached to the Lockheed-Goodyear proposal were sales figures, understated by about half. In the usual way of things, the contractors would have "recovered" their understated costs by charging for redesign and refinement needed to satisfy specification and requirements that varied substantially from those assumed for the proposal. Bradburn's "acceptance" of the main elements of the original proposal meant that there was little occasion for such maneuvering, and that in a "less cost" direction, for the most part.

To that point all had gone rather smoothly. But between Charyk and the Secretary of Defense there intervened one major review echelon, and on 15 November Bradburn learned that a potentially troublesome objection to Quill had surfaced during the final project review and approval process in the Pentagon. Dr. Eugene Fubini, then serving as senior technical advisor to Defense Secretary, Robert McNamara, had held up the release of program funds on the grounds that "we [the National Reconnaissance Office] intend to pay too much for the radar." Lieutenant Colonel E. J. Istvan, Bradburn's chief contact on the NRO staff, reported Fubini's protest that "APS-73 costs [only] a few hundred K." Fubini asked that the APS-73 project officer at [redacted] be solicited for a "more realistic" cost estimate.

From Fubini's viewpoint, concern seemed warranted. The program cost estimate that reached Fubini included a provision for [redacted] to buy five radar sets, about five times as much as for APS-73 radar sets then on procurement schedules. But, as Bradburn pointed out, APS-73 was not being bought *per se*; although modifications were to be held to the minimum needed to qualify the equipment for space flight, they would nonetheless be comparatively expensive. The cost estimates Fubini had objected to, Bradburn observed mildly, had in fact been both prepared and validated by [redacted] and although the [redacted] was charged as "radar payload" costs, it actually included engineering, fabrication, checkout, and launch services associated with the payload. Until firm bids became available, probably in January 1963, no better estimate could be composed.[8]

The response satisfied Fubini's objections; no more was heard from that quarter, and funds were released on schedule.

That problem disposed of, Bradburn met with Goodyear people at Phoenix on 20 November. Although the company had had no satellite experience, virtually all its contracts were with the USAF or the Navy's Air arm. Organizationally, [redacted] head of the Goodyear Arizona Division, reported directly to T. A. Knowles, president of the Goodyear Aircraft Company (home based in Akron, Ohio), a subsidiary of Goodyear Tire and Rubber Company. The Navy was responsible for industrial security and quality assurance at Phoenix (Commander [redacted] was the resident Navy representative) and the Air Force Procurement Office at Sky Harbor Airport in Phoenix handled auditing and accounting requirements.

Unlike Lockheed, Goodyear had very limited experience with the special security arrangements that characterized work on satellite reconnaissance. Bradburn noted at the onset of the Phoenix discussions that three aspects of the program were extremely sensitive: that a version of the RF-4C radar was being packaged for satellite use, that Goodyear and Lockheed were working together on a satellite radar project with Air Force funding, and that Goodyear had an Air Force contract to build a satellite radar. Initially, only 50 people in Phoenix could be briefed. In hopes of keeping exposure minimal, Bradburn decided that Commander [redacted] should not be informed of this new activity. (As events later dictated, his assistance became necessary and he had to be briefed.) Document control and visit requests would receive exceptional handling. Mail was to be sent to post office boxes and picked up by briefed individuals. Unless other business provided a sufficient cover, visits to Phoenix by the Air Force and Lockheed people would be arranged through direct contact with [redacted] Goodyear's Administrative Engineer. Visible project activity was to be covered by the story that it involved proprietary work called KP II--Knowles Project Number Two. (Goodyear had somewhat earlier performed work under a sensitive contract covered by the proprietary description, "KP I.") Such a cover would also ease procurement problems--radar components could be purchased "white" as commercial items--or so it was initially assumed, although there too problems were to develop subsequently.

Goodyear's draft work statement indicated a need for additional detailed technical specifications from the Air Force and Lockheed before manpower and cost estimates could be refined. For the moment, an estimate of expenditures for the first 60-day period was the best that could be provided.[9]

Security rules for Lockheed were defined the following day. Lockheed's white contract would not mention "radar" or "Goodyear"; the black version would be correlated by paragraph numbers to the white and would be specific.* Inasmuch as Lockheed had been doing "black" work of one sort or another for a decade, few new problems were likely to appear.

* The first security problem of Quill arose in the circumstance that Lockheed's original radar satellite notion had been "briefed" widely, before it "went black." In mid-November, the Strategic Air Command asked Lockheed to provide additional information regarding the Lockheed-Goodyear radar proposal. Bradburn vetoed the trip and got word to a witting SAC officer to "lay off."[10]

[redacted] work for the [redacted] due for routine contractual extension in March 1963, appeared easily exploitable to cover new activity. Funds could be readily transferred from the program office to [redacted] with no need for separate financial accountability. The [redacted] contract would be white, though with a vague work statement, but to insure that priority would be given the new paperwork, the [redacted] technical project officer and possibly the responsible procurement officer would have to be briefed.

[redacted] proposed work, costed at an estimated [redacted] included design of the synthetic-array radar experiment, considering in detail what radar parameters were required to obtain a successful demonstration, and preparing specifications for critical radar components. [redacted] was to be responsible for determining what azimuth resolution actually was obtained on the radar maps generated by the system and for analysing factors affecting resolution. The [redacted] was also to develop and construct a breadboard optical processor capable of achieving "the largest attainable compression ratio." If the theoretically predicted azimuth compression ratio anticipated in the experiment were not attainable, the largest technically attainable (probably 2000 to 1) would be the key factor in the design.* The processor was also to be designed to process data which might be obtained under conditions which were departures from the planned experiment, as might occur during actual orbit. Primarily, those discrepancies were to include departure from the intended orbit of the vehicle and from the intended orientation of the physical beam.

In addition to processing the radar data, [redacted] proposed to link the ground recording system to the optical display converters. The laboratory also suggested developing and procuring microwave beacons to observe and record emission histories. Lastly, the [redacted] proposed designing a test to determine the limitation on compression ratio imposed by the camera drives in the radar system.

[redacted] agreed to send to Bradburn by mid-December, two work statement drafts to be approved for content and security. One would be complete; the second would be "sanitized", omitting any reference to actual satellite operations or satellite derived data.

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* According to [redacted] an early objective of the program was to place emphasis on obtaining fine azimuth resolution to the greatest possible extent--optimally ten feet--while aiming for a more readily predictable 50 feet in range resolution. As factors determining range resolution were generally well understood, it was desirable to the experiment and potential future projects to determine whether adequate compression of azimuth-phase histories of targets could be realized.[11]

any reference to Goodyear, Lockheed, Special Projects Office, or the delivery of reports on "Design of Experiment". The problem of conducting covert work in [redacted] setting was not as easy as with Goodyear and Lockheed, but the basic procedures were much the same. As with [redacted] in Phoenix, [redacted] security officer, was not to be briefed unless it became unavoidable at some later time.* Uncleared personnel were not to be aware of the existence of an orbital radar experiment,** that satellite-derived data had been or would be processed by [redacted] or that the [redacted] had created a working relationship with Lockheed, Goodyear, Space Systems Division, or SAFSP.[13]

In mid-December, Bradburn learned that [redacted] would be able to revise its [redacted] contract to include Quill work before the contract expired in March. [redacted]

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* It did. Indignant that he'd been left out of the loop, [redacted] ignored strong hints to drop inquiries into security clearances at [redacted] for Quill work. He finally was briefed in April 1964.[12]

** Best laid plans had a way of being stepped on by idiots. [redacted] secure phone system, essential to his operations, was installed virtually in the dead of night and in a manner that was designed to be wholly unremarkable. On the following day the local telephone people asked the [redacted] how they wanted to be billed for all the special work, thus enlightening several administrative people to the fact that [redacted] had a special phone and was a consultant to the Air Force for some spooky operation.

[redacted] A few days later, Goodyear's draft work statement, specifications summary, and delivery schedule appeared. Not surprisingly, April 1964 rather than January 1964 had become the target for first flight. A formal Goodyear price proposal still was lacking, but Bradburn privately expected that it too would depart from the estimates earlier forwarded. When Quill had first been approved, four months earlier, Major Bradburn had very informally observed to Major John Pietz, with whom he then shared an office, that he expected the formal cost proposals to exceed preliminary estimates by a factor of two or more, and that his past experience with the several aspects of Samos led him to conclude that schedule revision would immediately follow the opening of negotiations for firm contracts. Discussing those expectations with General Greer shortly after being named project manager, Bradburn had elicited an ironic smile and full support for the suggestion that Bradburn's cost estimates be used in requesting program approval from Charyk, rather than some modest variation on the proposal estimates first received from Lockheed and Goodyear. Lockheed's proposal of mid-1962 had postulated a cost of [redacted] for a five-mission program; Bradburn calculated probable costs of [redacted] for three launches, but only if he could keep program objectives substantially unchanged from those approved by Charyk in November. There was no other way of preventing the cost growth that had characterized so many venturesome Air Force programs of the past decade. Concern for costs largely explained Bradburn's continued reiteration of primary program goals in discussions with contractors. He wanted all concerned to understand that in no circumstances would he consider incorporating either work additional to or technology newer than that originally contemplated.*

* In early 1963, General Greer's organization was battling a series of cost growth problems, virtually all of them having originated in faulty initial estimates by contractors and uncritical acceptance of optimistic projections by various program managers. Bradburn, who had by then spent nearly two years in Greer's plans and policy group, was fully aware of existing cost control problems and their origins. Colonel King, under whose guidance the Quill program had progressed from proposal to initial approval, was another whose skepticism about the validity of contractor proposals was pronounced and who shared with Bradburn the conviction that high-technical-risk programs entrusted to large management groups with complex reporting channels were sure to overrun. Quill and the P-35 (Project 417) weather satellite programs were the first SAFSP undertakings which conformed to the Greer-King philosophy, although Gambit was reconfigured to that model in 1963 after King became Gambit program manager. The archetype of small-staff, direct-management, risk-minimization was Corona, as originally organized. The most successful commercial practitioner was C. L. Johnson, Lockheed's leading aircraft design manager, whose products included the original F-80, the U-2, and the A-11.

In accepting the schedule revision, Bradburn pressed Goodyear to agree to build the transmitter-modulator unit in Phoenix rather than Akron as originally planned. Aside from tightening security, that move would enhance engineering control over the significantly critical unit, which was going to require extensive redesign for radiation cooling. Although protesting that key personnel would have to be moved from Akron, Goodyear agreed.[14]

By early January 1963, the status of the Quill budget was becoming clearer. Cost proposals from contractors at this point in time were slightly underrunning the tentative budget approved by [redacted], NRO comptroller, the previous November. Goodyear was estimating costs of [redacted] for fiscal 1963, [redacted] for 1964, and [redacted] for 1965 black funds. White monies to Lockheed's -800 contract were estimated to be [redacted] for 1963, [redacted] for 1964, and [redacted] for 1965. White funds transferred to [redacted] were expected to total [redacted] in fiscal 1963, the same in 1964, and [redacted] in fiscal 1965. Proposed total costs for the Quill contracts for fiscal 1963 were [redacted] (against an approved budget of [redacted] in fiscal 1964, [redacted] approved), and [redacted] in fiscal 1965. Total costs for all three contracts were estimated to be [redacted] November's approved budget was [redacted] In November, working with his own figures, Bradburn had estimated total program costs of at least [redacted] -plus boosters, launches, and orbital operations.

The three TAT/Agena D's with modifications, launch services, and three reentry capsules were additional costs to be funded under the [redacted] rather than as basic NRO costs. Agena D plus launch probably would cost [redacted] total; TAT plus launch-- [redacted] telemetry, tracking and command (vehicle)-- [redacted] and operations-- [redacted] Together, these added another [redacted] to the price of the program for a grand total estimate of [redacted] [15]

Meeting with [redacted] engineer in charge of the [redacted] contract at [redacted] and Major [redacted] late in January, Bradburn approved the white and black versions of the [redacted] but deleted some of the tasks [redacted] had earlier proposed. He had decided that the raw radar film should be developed by the Satellite Photographic Processing Laboratory, at Westover Air Force Base, Massachusetts, rather than by the [redacted] although the [redacted] would provide engineering liaison services. The ground-based photo recorders (for use with the readout mode of data retrieval) would be supplied by Goodyear rather than [redacted]. Lastly, Lockheed rather than [redacted] would build the microwave beacons.

Under the circumstances, Bradburn decided that no formal black contract need be written for the [redacted] group, since most of the very sensitive work had been assigned elsewhere. The white contract with [redacted] would therefore become the only binding agreement. Bradburn felt the motivation was so high at [redacted] and his contacts with them so frequent that any black statement assigning deadlines for the reports that comprised most of the remaining black effort there would be extraneous.

It appeared that [redacted] effort would cost [redacted] The total included [redacted] for system design and analysis of parameters; [redacted] for the data analysis and final report; [redacted] to design and build the optical correlator and another [redacted] to operate it; [redacted] to collect and analyze radar and beacon signals; and [redacted] to design and operate the camera drive evaluator. Of the total, [redacted] would be spent in fiscal 1963 and [redacted] in fiscal 1964.[16]

Basic arrangements having been made, Major Bradburn briefed Dr. Brockway McMillan in March and again in May 1963 (McMillan had replaced Charyk as Director, National Reconnaissance Office, early in March), describing the refined parameters for the Quill experiment as then designed and bringing him up to date on the status of Quill contracts, budget,and technology. It was Bradburn's first opportunity for describing fully the content of the program he had just created.

As defined in May 1963, the radar payload components of Quill consisted of (1) a transmitter-modulator which was basically a high-power radar frequency (RF) pulse amplifier; (2) an RF-IF unit, which generated a low-power RF pulse for the transmitter and received and compressed the reflected radar pulse; (3) a reference computer which generated timing and control signals (and transmission pulses) and synchronously demodulated the received intermediate frequency to provide video data; (4) a power control unit which controlled and switched power and generated regulated voltages necessary for the radar; and (5) a recorder which recorded the received video from the reference computer on film by exposure from the face of a cathode ray tube.

Goodyear had estimated that in its operating mode the radar system would consume 2700 watts of power. (Radiated effective peak power was 450 kilowatts, actual peak transmitter power 30 kilowatts, average transmitter power 250 watts.) The length of the transmitter pulse was 0.9 microseconds. By the use of pulse compression techniques, this was reduced to an effective pulse width of .06 microseconds. Pulse repetition frequency (PRF) had a 16-step variable range from 8216 to 8736 megacycles. The radar operated on a frequency of 9500 megacycles per second. Given such parameters, Bradburn estimated that slant-range resolution would be 50 feet and azimuth resolution 50 feet or better.

The Agena was to be injected into a near-circular orbit of 130 nautical miles (plus or minus 13 miles) at an inclination of 70 degrees. Precise attitude stabilization of the vehicle would orient the radar antenna so that the main lobe of the radar beam would be at a fixed depression of 55 degrees from the horizontal. In that attitude, the radar would map a slant-range interval of 5.95 nautical miles, or about ten miles along the ground.

Active radar operation was to be confined within the limits of the continental United States--and within the limits of control of the Vandenberg (California) and New Boston (New Hampshire) tracking stations.* The data obtained from the payload would be in the form of target echoes which would be synchronously demodulated to preserve both phase and amplitude aspects of the signals. The resulting raw radar map data (a doppler history of the illuminated terrain), would be recorded photographically on film in the recoverable capsule aboard the satellite. Simultaneously, the data signals would be transmitted over the wide-band data link to tracking stations, where they would be recorded both on photographic film and on wide-band magnetic tape recorders. After mission completion, the film record in the satellite would be recovered near Hawaii by air catch of the reentry capsule.

The radar antenna, being built by Lockheed, was a two-dimensional slotted-waveguide array, 15 feet long and 1.8 feet in height uniformly illuminated in both directions. The high-power output

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* One of the principal doctrinal problems of conducting a radar-in-orbit experiment was uncertainty about the reaction of the Soviet Union. Although there were various justifications for using radar sensors for overflight reconnaissance--all-weather, all-season, all-sun position capability encompassing most of them--and no wholly rational reason for concluding that active radar in orbit would be more objectionable to a target state than photography, the sensitivities caused by the U-2 affair of May 1960 still were evident in 1963.

The arguments against active radar surveillance of the Soviet Union fell into two categories. One had to do with the premise that nobody could object to surveillance if there were no demonstrable evidence of it. Because photography was wholly passive, there was

* (continued) (in theory) no way of providing incontrovertible evidence that surveillance was in progress--unless, of course, the owner of the reconnaissance vehicle acknowledged what he was doing, or somehow physical evidence of the activity fell into unfriendly hands. Putting the entire reconnaissance satellite program behind dense security barriers late in 1960 effectively precluded the first of those circumstances; the United States neither denied nor confirmed that it was flying reconnaissance satellites over Russia, although that intention had been loudly proclaimed on several occasions between 1958 and 1960. The possibility that the Russians might somehow recover a camera-equipped U.S. satellite, or enough of one to prove that it was a reconnaissance vehicle, had worried program managers since the first Corona launch in June 1959. Precautions against inadvertent descent of either capsules or camera sections within reach of Soviet recovery forces were extensive, and for several years they were believed to be effective. At least once in Corona experience, however, a largely intact capsule left a decay orbit and survived random reentry, and late in the 1960s sizeable shards of a Gambit mirror plus various bits and pieces of its electronic subsystems survived atmospheric reentry and were recovered in England. Enough capsules and orbital vehicles went astray in the 1960s to support reasonable speculation that some could have fallen into Russian hands--but nothing was ever said by the Soviets to suggest that had happened.

By its very nature, however, a radar satellite radiated recordable evidence of its purpose. That evidence might be sufficient to support a demand for a cessation of satellite overflight operations should the Soviet Union--or any other nation--make an issue of the matter; thus the reluctance to consider use of radar reconnaissance in satellite overflight of denied areas.

But there was another reason for such caution: Photographic satellites of the early 1960s were incapable of providing near-real-time information. They were superb instruments for doing targeting, for technical intelligence, for force structure evaluation, and for various other tasks with military significance. But only a radar satellite could conceivably do wide-swath bomb damage assessment without concern for season, cloud cover, or time of day. As no radar satellite could provide the detail of photography, it followed, then, that one substantial justification for operating a radar satellite of 1963 vintage (limited in definition and resolution) could be to have pulse of the radar was transmitted through the flat, phased-array antenna mounted on the side of the Agena, with the beam oriented perpendicular to the vehicle's longitudinal axis but depressed 55 degrees below horizontal. The beam was .36 degrees wide in the azimuth direction and 2.9 degrees wide in the vertical direction at the half-power points.[17]

Some of the early premises had to be altered early in the development program. [redacted] researchers learned, for instance, that bias errors generated by the Agena's attitude changes during flight were too large to be accommodated by the radar beam-width. To ensure that "zero doppler" direction in azimuth would result, a clutterlock or electronic beam steerer had to be designed within the reference computer. Although the clutterlock oscillator output could conceivably degrade date returns, [redacted] group

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* (continued) something in position for immediate bomb damage assessment-- which (according to the reasoning then current) could be interpreted to mean that a surprise nuclear strike was imminent. It was highly unlikely that any American president would order a preemptive nuclear attack solely on the strength of information that the Soviets were operating a radar satellite, but there was no such confidence in Soviet reactions were the United States to do as much.

There were other reasons for restricting on-orbit radar operations to the limits of the continental United States, the desire to keep the capability secret being one, but in the councils of Washington uncertainty about Soviet reaction was the principal cause of caution.

predicted that no serious degradation would occur except at initial lock-on.

McMillan was concerned about the assurance of obtaining qualitative data to support evaluation of radar performance. He therefore directed that ground resolution targets be provided so that a direct measure of radar resolution could be obtained from analysis of a finished radar map. He also suggested incorporation of an altitude rate change recorder in the vehicle. (Changes in altitude rates would degrade the azimuth resolution; if accurate rate data were available during evaluation, degradation from that source could be more readily identified.)[18] Bradburn made [redacted] responsible for resolution measurements and asked Lockheed to evaluate the feasibility of incorporating a rate recorder.

Bradburn also asked Lockheed to reverify reference computer specifications. Electronically, the most complicated component of Quill, the computer, was experiencing severe vibration problems which, in the RF-4C program, were causing some structural redesign. Quill program specifications required testing at 7.5 Gs; the original computer, designed for aircraft use, had failed at 3 Gs.

Less threatening but equally troublesome problems appeared in the procurement area in April. Goodyear began experiencing difficulty in buying government-inspected parts under commercial auspices. A tentative solution had been initially worked out by having [redacted] the local Air Force procurement specialist, verbally approve as "Contracting Officer" Goodyear's requests for the delivery of high-reliability components. The rationale "we might sell it to the government" was used to justify the implied use of government-approved items in what was represented to be an "in-house" company-sponsored program. That tenuous network collapsed in early May when a government inspector, who had been "officially" asked to release parts from a bonded warehouse for which he was responsible, called [redacted] Goodyear's security officer, to confirm that the commercial purchase order he had received actually supported a government contract. Routinely attempting to confirm that the listed parts would be used in work for the government, [redacted] fell into the local cover story--that they were needed to support a proprietary contract. Convinced that he had stumbled into something unsavory, [redacted] immediately blocked the purchase. An alarmed Goodyear executive hurriedly notified [redacted] who called [redacted] to verify that the work was indeed Air Force sponsored. [redacted] still sensing something highly irregular, said stiffly that he was obliged to notify his superiors in the Navy procurement chain. Seeing visions of a total collapse of security, [redacted] hurriedly alerted Bradburn, who instructed him to use some excuse--any excuse--to stall [redacted] until program office personnel could get to Phoenix. [redacted] grudgingly acceded to [redacted] plea to postpone any action until the following Monday. (It was then Friday afternoon, and Bradburn appreciated that a delay until Pentagon closing time would represent two days of grace.)

Colonel Ruebel and Major Bradburn flew to Phoenix on Sunday and enrolled [redacted] who agreed to support the project. They agreed that all future requests for verification of government interest in commercial purchase orders would be referred to [redacted] directly and that [redacted] would confirm their validity. [redacted] also agreed to assume the function of acting as cognizant security officer over the closed areas of the plant. No other Naval personnel were to be briefed or made cognizant of any special requirements.[19]

The potentially more troublesome problem of arranging, through the CIA, for General Electric to build and deliver three Corona-configured recovery capsules for use in the Quill experiment was resolved in the early Spring also. As with Lanyard and Gambit, CIA personnel were apprehensive about a security leak.

Discussions between SAFSP and CIA security specialists in a series of meetings led to agreement on 9 April 1963 that the procurement could proceed. The three capsules would be handled under Corona security procedures until their delivery to Sunnyvale and would thereafter be handled under Quill procedures.* Once that hurdle had been passed, the contracting and funding arrangements were quickly resolved.[20]

The first serious threat to scheduling expectations and Quill success occurred in early June 1963. Dr. McMillan had earlier expressed concern to Bradburn that arcing in high-voltage power supplies might become a problem. The original Goodyear specification, approved by Lockheed had established a level of .001 millimeters of mercury as the highest pressure in which the payload would operate. High-voltage arcing would not occur if that assessment were correct. Bradburn, nudged by McMillan, decided to insist on verification of Goodyear's estimate and asked [redacted] Project Manager for Lockheed, to cover that item during the next monthly program review in late June. Although he did not fully share McMillan's concern, Bradburn asked for a complete review of design considerations, parts qualifications history, and qualification testing for Lockheed- and Goodyear-furnished high-voltage supplies and any circuit points where high voltage existed.

* The differences were entirely academic.

Not until 17 July was the Lockheed team able to present its initial report, but the partial study was enough to indicate that a serious problem existed. Actual measurement revealed that pressures in and around the payload boxes could possibly be 10 to 100 times higher than anticipated. The greater molecular density thus suggested made it highly probable that high-voltage arcing would occur.

During the next several weeks, [redacted] and Dr. [redacted] of Lockheed evaluated redesign alternatives, considered testing difficulties, and weight penalties, and estimated the effect of the unforeseen rework on launch schedules. There were, fundamentally, three feasible responses to the arcing problem: pressurization, to drive molecular densities above the critical level; venting, to help pressures sufficiently low; and insulation by the use of a potting compound. Goodyear strongly recommended that the transmitter be pressurized (as had been done in the RF-4C version) and maintained that a pressure vessel could be designed and tested on the same time scale as a potting program, favored by Lockheed. Concerned by the conflict of opinions, Bradburn pressed the Lockheed investigators for more details and learned that Lockheed too would have recommended pressurization if the problem had been recognized at the outset of the program. He immediately ordered that preparations be made to pressurize the transmitter and any other modules that looked critical.

By the end of August it had been decided to pot and pressurize the transmitter, to use only potting compound in the recorder, and to provide for a back-up pressurization system that could be re-evaluated for need by mid-September. All concerned conceded that the transmitter-modulator and the recorder would present the most complex insulating problems, but that the high-voltage power supply being developed by Lear Siegler for Lockheed and the RF-IF unit might also be troublesome. Arcing problems in the control unit and the reference computer seemed to be controllable through the application of a void-free insulating conformal coating.[21] But it appeared that redesign and rework would cause a program slippage.

An associated difficulty appeared during the late summer of 1963. Colonel John Martin, head of the NRO Washington staff, advised General Greer that fiscal 1964 funds might be insufficient to cover currently projected Quill costs. He directed that the third Quill flight be deleted from the launch schedule and consigned as a payload spare. Requesting program re-costing by 10 August, Martin advised that although Quill was authorized to spend at previously approved rates through the first quarter of the new fiscal year, the program office should be prepared for a possible ten percent cutback thereafter. Martin assured Greer that he was proceeding "through OSD channels" to overcome the deficiency and that should those measures fail he would be notified immediately.[22]

At the end of August it was clear that Goodyear was eight weeks behind its original schedule and that official launch dates should be slipped by two months. Bradburn attributed one month of the slip to Goodyear's engineering and parts delivery problems and one month to the high-voltage redesign requirements. He estimated that the delay would cause costs at Goodyear to go up somewhat.* On the whole, Bradburn informed Greer on 30 August, Goodyear appeared to be doing a good job and Lockheed, although somewhat sloppy in systems engineering, was improving.[23]

By late September, the launch slippage had been officially confirmed and a new date for first flight--5 August 1964--had been targeted. Negotiations for the deletion of the third Quill flight were completed that month; the third Agena D vehicle and the Thor were cancelled, as were all Lockheed efforts on the third payload beyond

* It will be recalled that Bradburn's schedule and cost estimates were less optimistic than those proposed by the contractors and formally incorporated in contractor program plans.

the installation of the radar components in the payload-supporting structure. The third Quill was now treated as a spare payload that could be readied for launch within five to six months after the first Quill flight. Bradburn recommended that any further action on number three be deferred until the results of the first Quill flight could be evaluated.[24]

Early October 1963 saw a new design problem. Goodyear, attempting to meet the stringent vibration requirements of the program, concluded that the rigid payload rack mountings originally called for could cause payload performance degradation and called on Lockheed to provide vibration-resistant shock mounts. The initial approach, a simple substitution of mountings, proved inadequate. Payload racks in manufacture were stopped for redesign, a process that promised to take a month or more. A new interior distribution plan for the component equipment was called for, plus modification of the secondary barrel structure to provide the required structural stiffness. Lockheed's program manager anticipated the racks could be delivered by early December. Although that schedule would be tight, overall program scheduling should not be affected.

Goodyear and the special Lockheed high-voltage team were not enjoying similar success. Tests of the potting design in September and October had been disappointing. Poor surface preparation and improper cleaning and primer application techniques were blamed. But even after potting compound adhesion problems were disposed of, altitude testing disclosed the appearance of corona around potted components and cables. Lockheed recommended the use of light-weight closed-cell polyurethane foam as a countermeasure to corona generation in the RF-IF box. Extensively used to insulate and support high-frequency components, several such foam systems had been used by Lockheed on varactor multipliers similar to that Goodyear was building. The expedient worked, eliminating corona and break-down in the unit.

Elsewhere, however, foam as a corona suppressant was not successful owing to the lack of a primer that would act as an adhesive between the foam and the silicone-insulated lead wires and high-voltage components. External corona problems could also be eliminated by potting high-voltage components in metal cans, and eventually Goodyear decided to combine that expedient with the use of braid-shielded high-voltage cables and a conductive epoxy to interconnect the components.

For a time it appeared that the solution was working. Then one of the cylindrical cans containing the thyraton component burst at the seam because of potting expansion caused by the heat of component operation. Goodyear adopted a square can configuration to allow for bulging during thermal expansion and began to experiment with expandable-top cans. Such measures, when supplemented by the addition of an aluminum sling in the anode area (to reduce the bulk of the potting), proved successful. No further problems were experienced with thyratron potting, although repeated failures were to occur in later testing from other causes.

As a further precaution against high-voltage breakdown and corona, Lockheed resorted to venting of the payload boxes, one-inch diameter screened vent holes being cut on three sides on each box.[25]

By January 1964, Bradburn was able to assure Dr. McMillan that the high-voltage problem was under control. Arcing and corona phenomena in the transmitter-modulator had been eliminated. The backup pressurization vessel could be cancelled. The RF-IF unit, reference computer, control unit and recorder had all been successfully potted. Tests on the antenna model had indicated it would not need pressurizing.

Payload qualification testing was scheduled to commence in Sunnyvale in January and Goodyear was to deliver the first flight payload for acceptance testing in February. Payload final assembly and checkout would continue through April; full-scale system tests would begin in April and continue through June. A 5 August launch date still seemed to be achievable.[26]

The uncertainties of funding that had appeared several months earlier continued to be irritating but did not yet represent serious problems. Lockheed's Quill work still was being funded under supplemental agreement to another contract and Bradburn anticipated no change in that situation for the near term. As expected, Goodyear's need for additional money had to be acknowledged in February, and funds for [redacted] were sufficient only to support work there through September--if expenditures were continued at the rate originally contemplated. Bradburn advised [redacted] that in all likelihood no more than [redacted] additional could be made available through the end of the year, which meant that the [redacted] would have to stretch six months of contract dollars to cover nine months of work. No major technical problems were immediately apparent, although corona effects had again occurred in the high-voltage power supply and there were minor but troublesome difficulties with transmitter power and transmitter-modulator units in February and March. For the most part the response of program managers was to increase the tempo of testing. All of the radar units were scheduled to emerge from the manufacturing process in March and other principal elements of the payload were on schedule. A still-minor conflict of launch-pad scheduling caused Bradburn some concern in March, but he did not anticipate that it would become serious. (He planned to use a NASA gantry to mate payload and booster elements of Quill, and NASA had informally indicated a possible need for the equipment at about the time Quill was due to go into orbit.)[27]

From the time of program approval through March 1964, only five months short of the scheduled first flight date, Quill had been managed almost entirely by Bradburn, for the Air Force, and the three principal contractor project leaders: [redacted] (Lockheed), [redacted] (Goodyear), and [redacted]. Although he had reported frequently to Greer, and periodically to McMillan, Bradburn had for practical purposes exercised complete and near-exclusive control of the program. In March, Greer decided, as he told Bradburn, to call in some non-participating experts for a detailed overview of the work and of the operational readiness of Quill. In advising his contractor associates of the prospect, Major Bradburn emphasized that the review was "not an inquisition" and did not indicate dissatisfaction with any aspect of the effort thus far. But he observed that they could expect a "thorough scrubbing."[28]

The review had some undercurrents of interest that escaped the notice of those who merely read the eventual review report. It had begun, as Bradburn recalled, with Greer's usual report to McMillan, "Brad's doing fine," followed by, "wait a minute. How do I know he's doing fine. He's the one who's telling me." The "Tiger Team" to review Quill was Greer's rejoinder to his self reminder.

That the review would be thorough was guaranteed by the composition of the review team. Headed by Colonel Paul Heran, one of General Greer's most capable senior managers, it was composed largely of Aerospace Corporation specialists in reconnaissance radar. Unhappily for their state of temper, they had become "specialists" mostly through involvement in the "P-22" project--the "white" program conducted in part to provide a screen of cover for Quill.

P-22 participants had generally believed, until being suddenly briefed on Quill, that what they were doing was an extremely important prelude to what might eventually become a radar-on-orbit system. At the time of the briefing they learned that the radar-on-orbit system was not an abstraction but was in being--actually only about five months short of scheduled launch. They were, in Bradburn's recollection, "somewhat upset to learn there was a real radar experiment going on." They developed what Bradburn described as "an intense interest" in the quality of Quill.[29]

The specially appointed Aerospace team headed by [redacted] (which included several Air Force people) had instructions to look at payload and vehicle system designs; at qualification test history on new components; at power ground equipment design, availability and placement; at preflight checkout philosophy and the adequacy of test planning; at operational effects of recovery system changes; at competence of tracking stations and STC personnel to support the mission; and at tracking station equipment readiness. Briefed first by Bradburn, the team studied project documentation generated by the contractors before beginning meetings with Lockheed, Goodyear and [redacted] personnel in early April 1964.

The briefings concluded on 7 May and the report was forwarded to Greer shortly after.

Overall, the Aerospace group was optimistic that Quill would accomplish its main objective: obtain a high-resolution radar terrain map from an orbiting satellite within the designated short span of time. Nevertheless, they were less sure the experiment would contribute significantly to secondary objectives encouraging an operational future for an orbiting radar satellite. Secondary objectives had been stated as (1) evaluate the resolution potential and limitations of satellite-borne, ground-mapping radar; (2) evaluate the capability to retrieve the mapping information in real time by readout over a wide-band data link; (3) evaluate the feasibility of using satellite-borne radar for terrain reconnaissance; (4) obtain sufficient engineering information to determine the cause of a failure to achieve the primary mission, or portions thereof; and (5) improve future system design. Acknowledging that useful information would probably be obtained to support evaluation of the "resolution potential and limitations" of orbital radars, the team anticipated that the flights would not produce findings of greater significance. The tenor of the report was to recommend for the second and third flights a restructuring of mission objectives and emphasis. Inherent in these criticisms was distaste for the design philosophy that had guided Quill from its onset: use as many off-the-shelf components and as little modification as absolutely required. Perhaps no less could be expected of a group that until a few weeks earlier had considered itself to be leading the way to the first orbiting radar system.

The [redacted] group argued that "the use of a wide-band link for the retrieval of synthetic array radar data cannot be fully evaluated from the Quill experiment. Negative results will not be conclusive since the link was not engineered for this application. Positive results will not be conclusive since the quality of the Quill data is not representative of a high-quality radar."* And elsewhere: "Since much better mapping performance than the Quill radar will provide is technically possible, this program will not fully evaluate the potential of orbital radar for high-quality terrain mapping." The group concluded rather tepidly, that at its least the experiment would determine the cause of "catastrophic failures."[30]

* Italics added.

The first two recommendations of the report concerned work by [redacted] intended to define the sources of final image degradation. The reviewers urged that data be continually updated throughout the program, with equal consideration for data retrieval from the capsule and via the wide-band data link, and to post-flight analysis of the final map product. Bradburn agreed that the [redacted] researchers should devise both analysis and evaluation plans to satisfy the recommendations. But he did not accept uncritically a recommendation focussed on the secondary objectives of the mission. The Aerospace team felt that consideration should be given to flying Quill in a lower orbit (which would nominally improve the signal-to-noise ratio) and in a synchronous orbit (which would permit Quill to overfly the same target on successive days). While the planned orbit seemed to satisfy the primary objective of the experiment, the team felt it "marginal for the purposes of the secondary objectives."

Pointing out that a lower orbit would decrease the swath width and the payload operating times and thereby decrease the probability of seeing the resolution targets, Bradburn's people argued that "marginal enhancement" was not a sufficient justification for changing vehicle altitude. If the first flight were successful, lower flight altitude would be considered for follow-on flights. Synchronous orbits had been considered early in the program, but the necessary orbit adjust capability had been discarded because it ran counter to

Quill's "minimum modifications" policy. Bradburn felt that gains from overflying selected targets on successive days were not worth the extra effort--and cost--of incorporating orbit adjust capability in the Agena.

The committee's report took note of several problem areas already well known to Bradburn and the contractors as a result of qualification and acceptance testing. They included, among others, "thumping" in the transmitter-modulator, continued cracking of the potting compound after repeated temperature cycling, and cathode ray tube spot sensitivity to vibration effects. The reviewers also expressed concern that antenna testing had not been sufficiently intensive, urging comprehensive tests to verify the characteristics of an antenna they characterized as an advance in the state-of-the-art (because of its size and its required precision). On the whole, however, the acceptance and qualification testing program received approbation. The review team noted that system testers "appeared to be capable of giving the subsystems a thorough checkout; the schedule of retesting after major environmental tests was very good." But program reviewers also recommended that [redacted] prepare a system error budget to insure that tolerance margins did not become excessive, with a resulting degradation in payload performance.

In the end, the review team concluded that "no individual factor was uncovered which can be expected to prevent accomplishment of the primary objective of the Quill program." There were the usual injunctions urging continued diligent system engineering, analysis, and testing. The only significant remark in that category proposed "closer control of overall performance criteria by [redacted] eliminate the possibility of either over-specifying or under-specifying subsystem requirements." The committee also felt that the three principal contractors insufficiently appreciated the problems of interfacing such subsystems as attitude control, data link, and the antenna. But on the whole the review had to be considered approbatory of program conduct.[31] Comprising some 33 recommendations attended by lengthy comments, the report was submitted to General Greer, after which the program office and the main contractors spent much of May and June in responding by both comment and action.

In the meantime, Bradburn was more concerned with troublesome failures of the transmitter-modulator boxes in temperature-altitude simulation tests. During late March and early April, the first such complete test had been interrupted by power supply failure--

blamed on a faulty capacitor--and transmitter-modulator breakdown in altitude tests (charged to poor circuit design). After circuit redesign, a second altutude-temperature test of the complete payload began on 6 May. Results were reversed. The transmitter passed altitude testing but during the sea-level run the klystron failed. After reviewing test status, Bradburn concluded late in May that 29 August 1964 was the earliest possible launch date and that the next series of environmental tests was likely to uncover more difficulties. He recommended that 29 August become the new launch date target, but that the program office be prepared to accept further delays.[32]

In June the potting problem drew new attention. Lockheed had reported to Bradburn in late May that Goodyear had no written procedures or quality control for potting procedures. Bradburn's response was to notify Goodyear that he wanted standards written, and also to instruct the radar contractor to build eight of each potted item, to test all eight, dissect three, and if all three were good to pass the remaining five. Although the remaining difficulties seemed relatively small, the schedule of manufacturing and acceptance testing had been irreparably affected; in July it was necessary to specify an additional two-week delay in the scheduled first launch. Goodyear's hardware delivery problems were the principal cause of the slippage.[33]

One of the important residual uncertainties of component interface compatibility was resolved by late July. In a series of tests at its Santa Cruz facility, Lockheed ran comparison tests of a parabolic antenna and the flight antenna, both aimed at a corner reflector four and a half miles distant. Test criteria was to compare pulse transmitted and received through the horn or parabola with the pulse through array in order to measure distortion of radar pulse caused by the flight antenna. Third objective was to measure system-range resolution. Results demonstrated that the flight antenna was compatible with the basic radar generator, that the antenna did not cause pulse distortion, and that range resolution (with a corner reflector as a target) was better than 25 feet.

For all that reassuring news, the program incurred another schedule slip. Pulse-forming network redesign problems and klystron and plate choke potting failures in the transmitter-modulator forced a rescheduling of first launch to 24 October.[34] Then on 8 September, one of the klystrons in the transmitter-modulator failed during an altitude-temperature simulation checkout experiment. After replacement of the damaged elements, testing was resumed. Further component failures in the transmitter-modulator elements early in

October forced Bradburn (now a Lieutenant Colonel) to postpone the scheduled first launch once again, this time to mid-November. In order to verify confidence in the reliability of the first flight-qualified payload, he insisted on exposing the complete unit to five hours of simulated operations at the temperatures and pressures that would be encountered during the mission. That represented about ten times as much operation as the equipment would be required to produce during its initial flight, but Bradburn was convinced that nothing less than a "thoroughly run-in but not worn-out" approach would satisfactorily demonstrate the reliability of the troublesome components.[35]

Goodyear was unable to promise delivery of a test-qualified transmitter-modulator unit before the last week of November, unexpected problems developed in final tests of the film-drive unit of an orbital recording camera, and confidence in the design validity of the potted, shielded boxes earlier adopted to prevent high-voltage arcing was rapidly diminishing. (In November, Goodyear began the development of a backup design which discarded the shielding.) Although none of the problems was basic, all contributed to delay of delivery and testing schedules. A December first launch seemed achievable if technical readiness was the only criterion, but the classic problem of seasonal holidays introduced new scheduling complications. By mid-November, Bradburn was juggling holiday schedules, environmental test schedules, and launch pad (and satellite operations capability) availability in an effort to decide when a launch should be attempted. If Goodyear successfully completed altitude-temperature tests of the critical transmitter-modulator unit on 28 November as promised, launch could be attempted by 19 December--the last possible date for starting the mission without encountering holiday workload problems that might not succumb to a mere program manager's determination. After confirming his judgement in a meeting with Greer, Bradburn decided to push for a mid-December launch--which meant pressing Goodyear to complete the last of the environmental tests on or as close as possible to the critical 28 November deadline.[36] And he had another problem: although the essential validity of program funding remained intact, the recurrent delays in initial launch meant that both Goodyear and Lockheed were spending money that had originally been allocated to post-first-launch development and testing activities. (Lockheed calculated that about [redacted] had been expended in unprogrammed work in the period between the originally scheduled March 1964 launch date and the end of November 1964.)[37]

Late November and early December were thoroughly cluttered with technical and administrative problems that ranged from the absurd to the critical. Many months earlier, Bradburn had arranged matters so that no sudden influx of Goodyear people at Sunnyvale, Vandenberg, and the tracking stations would alter unwitting people to the imminence of an orbiting radar experiment, and in the event matters proceeded more or less as planned.* But there was late pressure to put Quill products in the Talent-Keyhole category, which meant making them available to a great many people who had been excluded from any knowledge of the NRO's plan to fly a radar satellite, and Bradburn had to divert his attention from technical to security matters, at least briefly, to prevent a breakdown of the original scheme.[38]

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* The arrangement was that Goodyear people visiting Sunnyvale would wear Lockheed identification badges and describe themselves as self-employed consultants to Lockheed if questioned about their status. At Vandenberg and the tracking stations they were given credentials identifying them as consultants to the Air Force, no corporate affiliation being specified. Because friends and families were not permitted to know that airborne radar specialists were involved with space programs, various cover plans had to be devised that would conceal the whereabouts of engineers who while actually visiting one of the space stations was nominally somewhere else. It would be interesting to learn how successful Goodyear people were in convincing spouses that their frequent out-of-touch trips were as innocent as represented to be.

The transmitter-modulator tests finally were completed successfully on 2 December, resolving the chief remaining uncertainty of Quill qualification. Delayed delivery of Philco-produced data-link equipment to the Vandenberg tracking station briefly threatened postponement of launch pad system checkout, but by 5 December that too was settled happily. (Actually, several items of critical equipment were delayed in delivery, but Goodyear's transmitter-modulator was the pacing item through the last three months of pre-launch testing.) The last really troublesome issue revolved around the preposterous question of the high-temperature behavior of that common household item called Mystic tape--and for a time it threatened to delay the launch once again.

"The Mystic Tape Problem" had its origin in the temperature sensitivities of the main batteries in the Agena. In the wake of several battery failures and near failures in Agena flights earlier in 1964, Lockheed engineers had narrowed the allowable launch window for Agena-payload missions (thus changing the sun exposure characteristics of standard missions) and had redesigned the external paint pattern of the spacecraft. Black paint was applied to those portions of the vehicle where heat absorbence was desired, and reflective material elsewhere. The reflective material selected was adhesive-backed aluminum tape--Mystic tape. It covered 104 of the 255 square feet of the outer surface of the Agena's forward equipment compartment. Two weeks before the now-scheduled 21 December launch of Quill, a Vandenberg technician placed one of the Mystic-taped removable panels of the Agena under a heat lamp. It blistered. Although the manufacturer guaranteed that the tape would adhere to external areas where temperatures would not exceed 750 degrees (Farenheit), materials specialists at Vandenberg quickly determined that molecular outgassing in a low-pressure environment would cause blisters to form on the underside of a tape at temperatures of only 300 degrees. When blisters became large enough to extend to the edge of a piece of tape, the trapped gas escaped and the tape collapsed, reattaching itself to the surface--unless the blister reached the forward edge of the tape while there was a forceful airflow along that edge. In that case, it could conceivably fold back and tear away in the airstream. If enough tape broke away, battery overheating could result and mission success would be imperiled. It was a classic horseshoe nail phenomenon. Happily, the vulnerability came to light before launch rather than in a post mortem. Launch base personnel were instructed to tuck the tape over the leading edges of all removable panels and to cover with stainless steel strap all those edges where there were no removable panels. Extensive tests confirmed that the reflectance properties of the thermal control surfaces would remain within required tolerances if that precaution were taken.[39]

Simulated launch and flight tests and other compatibility tests at Vandenberg during the first half of December uncovered only a few minor glitches--a defective bearing in the film supply spool in the recorder, transients in one of the power supply units among them--but these were readily fixed and no significant malfunctions were detected in the integrated satellite system. The completion of the countdown, launch-minus-three-days checks, and the horizontal simulated flight operation completely revalidated flight vehicles and payload. The only exception to a complete functional check was radar transmission through the flight antenna, which had been validated in earlier testing. Every other payload function was exercised in the final flight configuration.

On 19 December the gantry was removed and because rain was falling a protective polythylene cover was placed over the forward (payload) sections of the Agena. High winds during that night caused the cover to repeatedly slap against the newly-taped surfaces. When the gantry was repositioned the day before scheduled launch and the "protective covering" removed, launch personnel discovered that most of the normally shiny aluminum tape surface had been degraded to a dull and in some areas almost black finish. Additionally, finely divided aluminum had been transferred to adjacent painted surfaces. Happily, Lockheed's optical surface comparator was still in the gantry, so new measurements could be taken at once. Less happily, the measurements indicated that the solar absorbtivity of Mystik tape surfaces on the cylindrical sections of the vehicle had been increased by as much as 300 percent! Tape on the conical section had not been unacceptably degraded. But clearly large sections of tape would have to be replaced and painted surfaces cleaned.

Beginning with the surfaces most critical to battery temperatures, technicians replaced approximately 75 percent of the tape earlier installed on removable panels and cleaned the painted surfaces with distilled water and a mild abrasive soap. Ten hours before scheduled launch, the rework was completed and the gantry was removed. All but about 15 square feet of the degraded tape had been replaced, but as a further insurance measure the normal two-to-four-hour launch window was reduced to 48 minutes at midday, thus lessening the time during which the reflective sections were exposed to direct solar radiation.[40]

On 21 December 1964 at 11:09 Pacific time, Quill vehicle 2355 was launched from Vandenberg Air Force Base and injected into an orbit of 70.1 degrees inclination with an 89.4 minute period. All subsystems functioned properly. Tracking station personnel verified the operability of the data-link equipment during Quill's seventh orbit, and on the next passes over New Hampshire and Vandenberg radar mapping was attempted. All were successful. Diagnostic telemetry returns indicated correct functioning of all payload components. Both stations recorded video information. Operator's displays showed the expected patterns. Ground recording equipment operated by [redacted] scientists showed the radar transmission to be radiating strong signals. [redacted] reported to Bradburn that a quick look at readout data from Pass Eight on a projector showed successful ground painting. A reconnaissance aircraft scheduled to photograph the "painted" ground swath was unable to fly because of poor weather in New England, but otherwise all went perfectly. Recovery was planned for 22 or 23 December, the final decision hinging on the higher priority of a Corona capsule also scheduled for recovery on one of those days.

Reports from the Quill command post at Sunnyvale on 22 December indicated continued mission success. [redacted] reported that data read out from Pass Eight which at first seemed to be severely degraded were susceptible of improvement if the correlator were refocussed by hand. He also told Bradburn that [redacted] receivers had captured a successful wide-band recording of transmitted radar pulses confirming proper phase and amplitude characteristics and that a mobile narrow-band recorder positioned at the [redacted] [41] had verified the correct functioning of the antenna.

The payload continued to operate nominally through orbit 25, using 316 feet of film. Reporting to Greer on subsystem activities, Bradburn indicated that radar frequency power output and high voltage were well within predicted limits. Minor engine chamber pressure fluctuations during boost thus far represented the only mission anomaly, although heavy cloud cover was causing some slightly out-of-specification roll excursions when the horizon sensors were turned on. (The horizon sensors, providing long-term pitch and roll stabilization for the vehicle, were not used during radar operation. Their response to cold clouds could conceivably cause instabilities which could lead to serious degradation of azimuth resolution.)

A second attempt to photograph terrain as it was being viewed by radar ended in another weather-induced flight abort of the assigned aircraft, but satellite operations continued to be flawless. When Corona flight controllers decided to continue their change in orbit until 23 December, Bradburn ordered Quill recovery to be conducted one day earlier.[42]

As with the balance of the mission, capsule recovery was routine. After retrieval and despooling, the film was dispatched to the special processing laboratory at Westover, arriving during the morning of 24 December 1964.

Quill's radar system was operated for a total of 14 passes over the continental United States between 22 December and 26 December. Thereafter electrical power and stabilization gas exhaustion prevented further experimentation and the Agena was deliberately destabilized for destructive reentry. It reentered over the South Atlantic on the morning of 11 January.[43]

As General Greer later wrote, "The flight of the satellite when it came in December 1964 was almost anti-climatic. So close was the system performance to that determined in tests, so nominal was the operation, so professional was the handling of the satellite by the Satellite Control Facility, [that] a participant had to remind himself that this was not just another rehearsal . . . The result was a 100 percent successful mission in quality and duration."[44] What remained was to evaluate the Quill take and to determine the immediate future of satellite-borne radar systems.

On 5 January 1965, Bradburn and the chief contractor project managers presented a P-40 "Quick Look" briefing in Washington.* The primary objectives of the mission had been fully satisfied. Initial evaluation of final map quality, using recovered data film, revealed azimuth resolution at 10 to 15 feet and ground range at 60 feet, far exceeding the project's resolution requirement of 100 feet or better. There had been no vehicle or payload system malfunctions of any significance.

Bradburn proposed postponing the launch of the second Quill vehicle until the several contractors could complete an intensive

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* With Bradburn were [redacted] (Lockheed), [redacted] (Goodyear) and [redacted].

engineering evaluation, a process that would take almost six weeks. Decisions on whether or how to operate the second and third flight systems could be made on the strength of the initial analysis although a comprehensive engineering analysis would last for three months. McMillan promptly approved both proposals.

Final reports on the first Quill mission involved a quantity of material available for analysis in addition to the radar maps: telemetry records indicating vehicle attitude and radar performance, engineering specifications and preflight test results on equipment, computer best-fit orbit and attitude history, weather data, ground measurement of azimuth beam pattern, one-way pulse recordings, results from the corner reflector layout at [redacted] post-flight aerial photographs of target area, and radar maps of target areas taken with [redacted] airborne radar equipment. One of the most critical post-flight evaluation reports was that prepared by [redacted] indicating the extent to which Quill's primary and secondary goals had been met. Responsible for preparing "the highest possible" final radar maps from both recovery and readout data, [redacted] measured range and azumith resolutions and estimated system dynamic ranges. That analysis revealed the relationship of measured results to the radar design and performance parameters of Quill, propagation conditions, vehicle behavior and data link performance.

The audience in the Pentagon on 5 January was able to view samples of the Quill output maps in the form of photographic prints and negative transparencies. Three different sets of maps were displayed. First were maps made from the recovered data film, then maps reconstituted from tracking station photographs of the signals from a wide-band data link, and finally maps made by playback of magnetic tapes of the data link signals. The recovered film provided the highest quality maps, and the magnetic tape playback data the poorest--because both data link and tape recorder signal losses were involved. But all were "good."* Bradburn was voluble in his praise of the rapidity and excellence of processing of recorded and recovered materials.

Although there was little explicit discussion of when, or if, another Quill mission would be flown, neither Greer nor Bradburn saw any need for one. Results had so thoroughly exceeded reasonable

* Sample photography, extracted from the final report prepared by [redacted] are reproduced in an appendix volume of this history. All radar imagery was impressive, pictures of Phoenix, Chicago, and Richmond (Virginia) being particularly interesting for the detail they contained. Barges, ships, and railroad trains were readily identifiable through cloud cover, fog, and rainstorms. So were fine geographical details: hills, dams, streams, highways, islands...

expectations that there seemed no justification for collecting additional data.[45]

Nevertheless, until a decision was announced the program office continued to study modifications that might improve the quality of returns from a later Quill mission. Quill contractors urged that a second experimental flight carrying modified equipment be attempted in September 1965. Bradburn thought the probable gain too slight to justify the cost--and so advised Greer. On 11 February, Greer told McMillan that the feasibility of radar reconnaissance had been "amply demonstrated" and that additional launches should not be scheduled until there was agreement on "desired operational use." He endorsed Bradburn's recommendation that Quill be closed out with the final reports due in April and that Quill hardware be put in storage, the vehicle equipment at Lockheed and all black radar hardware and ground equipment at Goodyear. Any decision to reactivate equipment for a second launch would require a minimum of nine-months lead time, but Greer felt this break in the continuity of the project was justified in view of the "thorough evaluation" that would be given to the first Quill's returns in the meantime.

Greer carefully refrained from advocating the termination of satellite radar studies, but he argued that Quill data made it feasible to proceed using aircraft and ground tests, laboratory experiments, and other non-specialized satellites. "We have provided a good basis for further exploration of an operational system. This work should proceed when the conclusions of your evaluation committee are available," he told McMillan, who agreed.[46]

Although Quill hardware was destined for storage, either permanently or temporarily, and plans for additional launches of the original Quill-configuration satellites had all but been cancelled, there still remained the original issue of whether radar satellite bomb-damage assessment or crisis management systems should be developed and deployed. And still to be formally assessed by intelligence specialists was what the Quill experiment had contributed to a better understanding of both requirements and technology. Brigadier General James T. Stewart, who succeeded Brigadier General John L. Martin as chief of the NRO staff, has suggested in October 1964 that a formal evaluation team be immediately organized to determine means of "maximizing the knowledge gained from the Quill feasibility demonstration."* At that point Bradburn and Greer were much more concerned with resolving equipment qualification problems than with planning for the evaluation of results that might

* Italics added.

or might not be returned by the first--or the second or third--Quill mission. Stewart wanted to schedule--and organize--a full-scale operational utility analysis. Greer, in the circumstances, urged that "we should avoid fanfare over this effort," that Quill as a system had absolutely no known operational utility or adaptability and should continue to be treated as an R&D project, and that the NRO should wait ". . . until after we have recovered and reconstituted something worth evaluating from an intelligence viewpoint . . ." before setting afoot any elaborate evaluation effort. It was all consistent with his position on Gambit and reflected the pragmatism of experience with the wholly unsuccessful Samos E-5 and Samos E-6 systems, only recently cancelled. Greer convinced Stewart, and the matter dropped from sight for several months.[47]

Owing in part to the increasing acrimony of CIA-NRO relationships in the early months of 1965,* evaluation of Quill findings remained somewhat fragmented until April, being mostly confined to participating contractors and to informal review by various intelligence community personnel specified by the USIB's Committee on Overhead Reconnaissance. Bradburn, briefing senior CIA reconnaissance

* See Volume V, pages 180 et seq.

people early in March, explained the limited circulation of Quill's radar imagery (the National Photographic Interpretation Center had not yet been authorized to view the product) in terms of constraints imposed from USIB. He was advised by Dr. A. D. Wheelon, the CIA's Deputy Director for Science and Technology, that "... earlier CIA reservations were mainly procedural, and [that] there had been no intent to delay the evaluation," --following which an Ad Hoc Quill Intelligence Evaluation Team actually was formed. It met first in April, including representatives of the Defense Intelligence Agency and the several military services as well as CIA, NRO, and NPIC (which provided the chairman).[48]

Between April and June 1965 there was detailed consideration of a proposal for ". . . modifying the existing Quill system in storage to provide range resolution comparable to azimuth resolution . . . for a Quill mission over the USSR using the capsule recovery technique only," but like the several similar proposals of the early 1960s, it eventually fizzled into nothingness. Goodyear was convinced that Quill equipment could be modified to produce a slant-range resolution of about 25 feet but nobody in authority seemed to be much interested.[49] The Strategic Air Command was the chief prospective customer, and all the earlier reasons for avoiding the use of satellite radar over the Soviet Union weighed against SAC urgings. A special USIB committee that looked into requirements in 1967 emphasized again that quite apart from rather demanding technology, ". . . possibly an even more critical disadvantage of side-looking radar is that it actively transmits electronic pulses which will be detected and which might well become the basis for diplomatic protests of such serious nature that US policy makers would deny permission to employ the system in peacetime." Given that the acquisition of basic radar data needed for the long-term support of post-strike, bomb-damage assessment operations "would require many missions and much activity . . ." there seemed little doubt that "protests would probably not be long in coming."[50]

The prospective costs of creating a radar satellite network for possible use in crisis management operations served as a deterrent to the approval of a formal operational requirement for such a system. It was impossible to evade the realization that a large complex of interlinked ground stations supporting a veritable fleet of satellites was necessary to perform the sort of daily coverage, near-real-time readout that crisis management required. Further, if crisis reconnaissance were to be an assignment of a radar satellite contingent, a comprehensive data base on "relevant installations" would have to be prepared and maintained "on a current basis," in the words of a COMOR (Committee on Overhead Reconnaissance) report assembled only months after Quill results first became available. That, of course, implied a requirement for peacetime overflight of denied areas by active radar satellites, and the fundamental policy objections to that sort of operation changed little during the 1960s.[51]

The basic attribute of side-looking radar that made it attractive was its synthetic aperture mode--but that also represented its principal shortcoming. Side-looking radar had a limited ground swath which could not be effectively broadened without compromising weight, power, and antenna-size factors. The system had limited fore and aft viewing capability and an inevitable blind spot directly below the carrier vehicle, the consequence of having to "look" at an oblique angle in order to obtain range resolution. In its 1967 study (published in 1968), USIB estimated that continuous coverage from an altitude of 200 nautical miles would require "in excess of 32,000 vehicles . . . on orbit simultaneously"--which also suggested that rather a large number of readout installations might be needed to exploit the potential of 32,000 satellites. Raising operating altitudes reduced the numbers needed to about 6500 but imposed requirements for from 10 to 1000 times the radiated power required for reconnaissance from 200 miles, power being dependent on the physical aperture of the antenna system. Because synthetic aperture radar relied wholly on antenna motion for its azimuth effectiveness, side-looking radar could not be adapted to operate from synchronous-orbit vehicles.[52] Quill had worked, and worked almost precisely as planned. But that radar could be effectively operated from orbit remained only one aspect of a complex problem that involved requirements, applications, technology, international politics, and needs for vast funds. It was particularly interesting that the feasibility demonstration finally cost roughly [redacted] or some [redacted] less than Bradburn had estimated when first confronted with the project, but that an operational system would surely have cost billions. (The [redacted] difference would have been expended had two more missions been flown, of course.) It was also interesting that the "Phase Alpha" research and development project conducted in concert with Quill tended, by 1965, to look more and more like a sophisticated Quill. When taxed with the NRO's apparent lack of interest in exploiting the capabilities of orbiting radar, Dr. A. H. Flax, McMillan's successor as Director of the National Reconnaissance Office, was wont first to cite the "Phase Alpha" work and its follow-on as evidence of a continuing NRO investment in radar satellite research and development, and then--if the issue were pressed--to point at Quill as evidence that the fundamental feasibility work had been very successfully conducted and to suggest that requirements, technology, funds, and politics were problems that should be effectively addressed before new experiments were undertaken.[53]

The Quill program had been designed to provide data that would permit evaluation of the technical feasibility of employing what Greer called "this valuable new military instrument for the furtherance of national policy." Although initial plans had assumed that the relevant data could be obtained by 1965, they had also assumed that three to five missions would be needed to provide the information. In the event, the first mission was delayed by seven months, but no additional missions were needed and the derived data were "of even better quality than had been expected from the most optimistic estimates." The best estimate of the cost of obtaining those data was about [redacted] the result was obtained for [redacted] and should further flights have proved advisable for any reason, fully flight qualified hardware was available. (Some of the findings were passed to NASA for use in lunar exploration programs and the hardware was as readily convertible to NASA applications as was the much heralded lunar survey camera system derived from Samos E-1 experience.)

In Bradburn's view, the spectacular success of the effort was in considerable part a result of the special circumstances under which it had been conducted--tight security being a principal element of those circumstances. Pressures for information, advice, and participation by the many agencies interested in radar satellites would have incredibly complicated what had been a very difficult development program. In an epilogic meeting with several of the project participants, Bradburn also attributed program success to "individual efforts by individual people, each . . . a specialist in his area." And he skirted the treacherous path that stemmed from the all-too-common misapprehension that a successful development team and a successful development approach could be channeled, fundamentally unchanged, into some new and different problem. Proposals for program continuance and for new experiments with modified Quill equipment still were current when Bradburn closed out the last of the Quill tasks, the final reports. Neither he nor Greer--nor Greer's successors--ever gave them serious consideration.[54]

N.B. Notwithstanding the general reluctance of senior American officials to approve the development of operational radar satellites and the continuing premise that active radar surveillance might be politically unacceptable to the Soviet Union, that nation in 1968 began its own radar satellite development program and by 1971 had operational vehicles in orbit. They were generally similar to Quill in configuration, employing synthetic-aperture radar and relying on readout for data retrieval. (They entered semi-equatorial rather than polar orbits, however.) But the Soviet satellites were--at least ostensibly--designed and used for ocean surveillance, for spotting and tracking ships and fleet movements. The radar seemed to be low resolution in character. Thus they did not violate the principles honored by American policy makers; operation over non-Soviet-bloc land masses was not attempted. Nonetheless, the apparent capability of the Soviet ocean surveillance satellites to perform some level of bomb damage assessment, or even for low-grade crisis management assignments, could not be disguised. It was real enough.

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34. Briefing record, pres by LtCol D.D. Bradburn to MGen R.E. Greer, 11 Aug 64, subj: P-40.

35. Briefing record, pres by LtCol D.D. Bradburn to Dr. B. McMillan, D/NRO, 7 Oct 64.

36. Briefing record, pres by LtCol D.D. Bradburn to MGen R.E. Greer, 13 Nov 64, subj: Progress Report P-40.

37. Bradburn's notebook, 30 Oct 64.

38. MFR, prep by Maj D.D. Bradburn, 19 Dec 63, subj: Security Procedures for GAC Personnel at Sunnyvale, VAFB, VTS, and NHS; Bradburn's notebook, 22 Oct 64.

39. Rpt, "Vehicle 2355 System Report," Vol II - Engineering, prep by LMSC, 31 Mar 65.

40. Ibid.

41. Msgs, [redacted] 21 Dec 64; [redacted] 22 Dec 64; [redacted] 22 Dec 64; [redacted] 22 Dec 64; [redacted] 23 Dec 64; all msgs from Sat Ops Cen to DNRO and SAFSP.

42. Msgs, [redacted] 23 Dec 64; [redacted] 23 Dec 64; both STC to DNRO and SAFSP.

43. Msg, [redacted] 24 Dec 64, STC to DNRO and SAFSP; TWX, TWOP-5, 6594th Aerospace Test Wing to SAFSP (LtCol D.D. Bradburn), 12 Jan 65.

44. Recommendation for Decoration, MGen R.E. Greer (Dir, SAFSP) to USAF Mil Pers Gp, 26 May 65, subj: Legion of Merit for LtCol D.D. Bradburn.

45. MFR, prep by LtCol D.D. Bradburn, 12 Jan 65, subj: Quick-Look Briefings on P-40 Results; Bradburn interview, 7 Jan 74.

46. Msg, [redacted] MGen R.E. Greer, Dir/SP, to Dr. B. McMillan, D/NRO, 11 Feb 65, subj: Disposition of Quill Hardware; Msg, [redacted] BGen J.T. Stewart, Dir/NRO Staff, to MGen R.E. Greer, Dir/SP, 16 Feb 65, no subj.

47. Msg, [redacted] BGen J.T. Stewart, Dir/NRO Staff, to MGen R.E. Greer, Dir/SP, 1 Oct 64, msg, [redacted] MGen Greer to BGen Stewart, 5 Oct 64; Msg, [redacted] BGen Stewart to MGen Greer, 12 Oct 64.

48. Msg, [redacted] BGen J.T. Stewart, Dir/NRO Staff to MGen R.E. Greer, Dir/SP, 24 Dec 64, MFR, prep by LtCol D.D. Bradburn, 15 Mar 65, subj: QUILL Presentations to SAC, SAFSL, CIA, DDR&E, and NASA.

49. Msg, [redacted], BGen J.T. Stewart to MGen R.E. Greer, 21 Apr 65; msg, [redacted] [redacted] to LtCol D.D. Bradburn, 11 May 65, subj: Performance Estimates of Modified KP-II Equipment; msg, [redacted] BGen Stewart to MGen Greer, 9 Jun 65.

50. Rpt, USIB/Comirex Rpt USIB-D-46.4.3 (COMIREX-D-13.74), "Requirements for Image Forming Satellite Reconnaissance Responsive to Warning/Indications Needs," 5 Jan 68.

51. Memo, [redacted], ExSec, COMOR, to COMOR, 24 Jan 66, subj: Draft of Subject Paper Looking into Suggestions Made at Special COMOR Meeting of 24 January 1966.

52. Rpt, USIB-D-46.4.5, 5 Jan 68.

53. Bradburn interview, 7 Jan 74; Recommendation for Decoration, MGen R.E. Greer to USAF Mil Pers Gp, 26 May 65.

54. Bradburn's notebooks, 10 Mar, 28 May, 8 Jun 65.