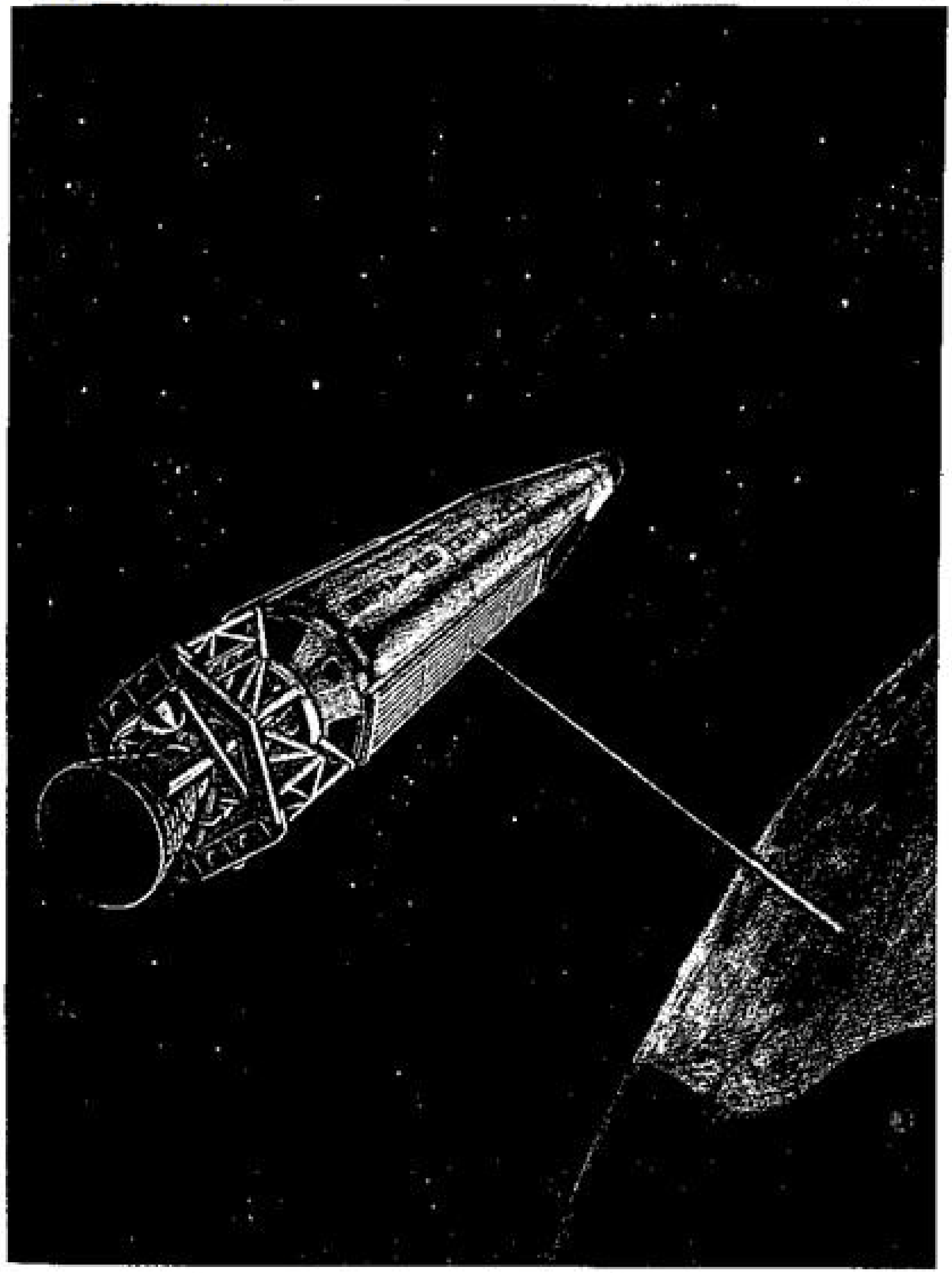
NRO 50th Anniversary Lecture:
Presented by Dr. Jeffery A Charlston on 14 August 2011
QUILL: A 1964 NRO Experiment in Off-the-Shelf Radar Technology

Announcer: We all know that birds have Quills or feathers that help them fly, but I bet you didn't know that NRO has Quills as well. QUILL, was an early NRO satellite program that demonstrated potential for space borne radar imagery and the capability to directly downlink imagery data in real time. Our guest today, Dr. Jeffrey Charlston is here to tell us more about this early feather in NRO's cap. Dr. Charleston is chief of the State department's paper record declassification review program. Before his current post, he worked on NRO's Information Access and Release Team where he drafted the declassification guidance for GAMBIT and HEXAGON family of systems and the pending guidance for the declassification of QUILL. Prior to that, he served as the senior historian at NRO's Center for the Study of National Reconnaissance. His latest article, "What we officially know: 15 Years of Satellite Declassification" appeared in Quest magazine. Dr. Charleston also brought a publication he authored entitled, "QUILL: A 1964 NRO Experiment in Off the Shelf Radar Technology". These publications are over there on the table and I encourage you all to take one on the way out, but do note that these are classified. Ladies and gentlemen please join me in welcoming Dr. Jeffery Charlston. [Applause]

Dr. Jeffery A. Charlston: Okay, I'll ask you to bear with me this morning... I have not seen the slides since I left the NRO so I'm going to be sticking very closely to my notes. There is an ulterior motive for being careful about the guidance as well. As a harbinger of things to come, Quill's existence had to remain classified entirely until space based imaging radar, the U.S. intelligence community's use of it and the organization that ran such systems were all declassified. That's now the case and QUILL is now poised for declassification. The story of QUILL is one of absolute success it proved to be well ahead of its time. It's a 1964 mission. At the time we were still experimenting with photographic systems. The CORONA system is up and running, QUILL is out there with Radar before anybody even suspected, or suspects in the unclassified environment, that we were doing these sorts of things.

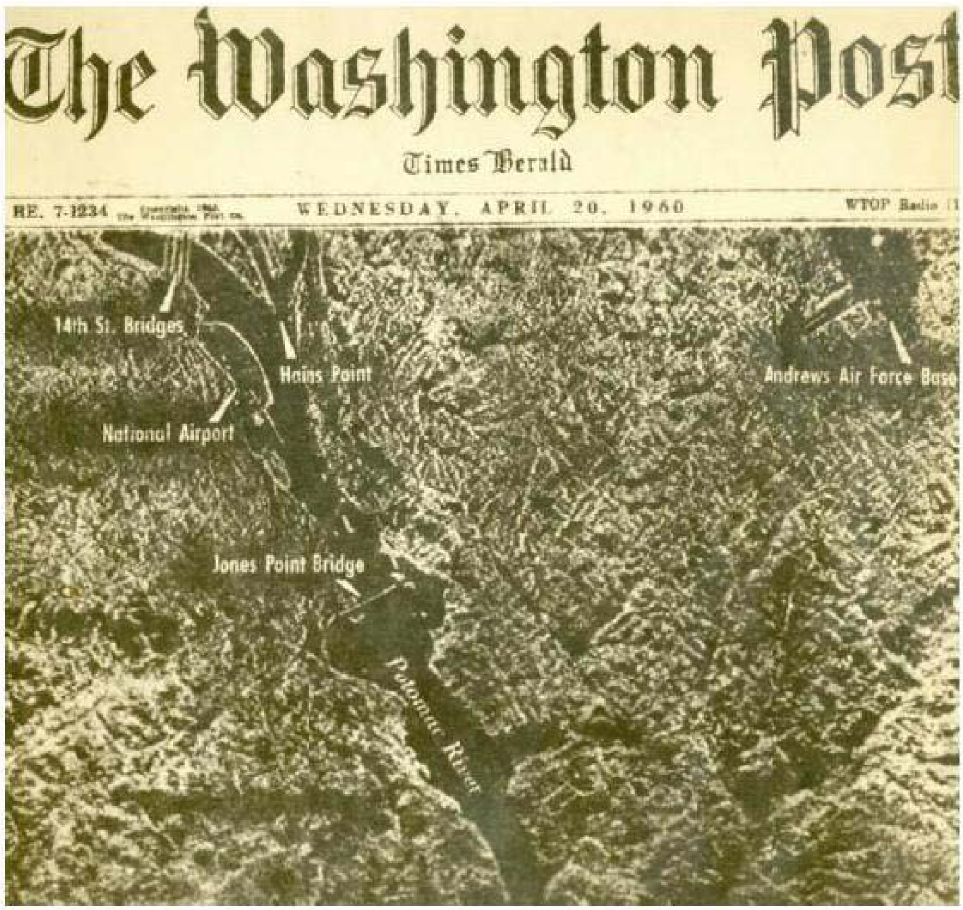


Quill remains relatively unknown even inside the intelligence community, it flew a single time. But in addition to being the first radar imaging satellite in the world, it proved to be a remarkably cost effective experiment with off the shelf technology. 1964 the NRO’s talent is clearly displayed taking off the shelf materials Corona hardware, Air Force hardware combining them into an absolutely new capability in space.

The program records were destroyed at the end of the program. All the remains of the QUILL program itself are some final reports, and a handful of scattered records. So what you’re going to see is a little bit different from the typical briefing. We don’t have a lot of surviving information. What the slides behind me will be is examples of the sorts of information that historians and declassifiers work with in understanding old programs and deciding what can and can’t be said to the public.

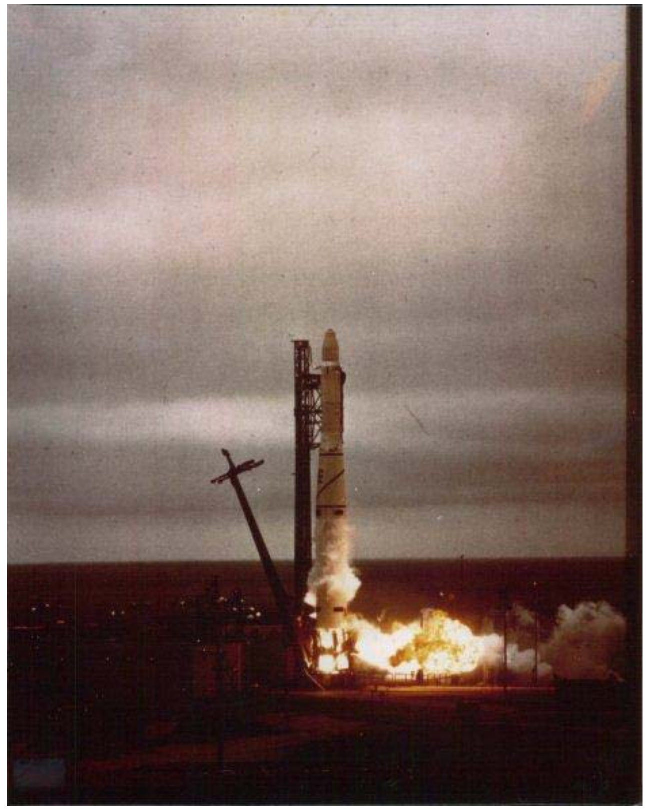
Aviation Week and Space Technology 69:10 (8 September 1958), 100-101.

The first surprise is that there is nothing new about the concept of space borne radar. Just 10 days after the launch of Sputnik, 14 October 1957, the public became aware of the Air Force’s program Weapons System 117 Lima [W117L]: The ancestor of all of our current systems. When W117L was disclosed to the public it was said it will, quote, “It will carry television photographic cameras, infrared spotter or radar scanner system.” Speculation already existed in the public in 1957 that space borne radar was possible at some level. The radar scanner system that they are talking about is what is known today as Synthetic Aperture Radar. It’s impossible to orbit a large enough antenna to collect a good radar image. What we do is generate a synthetic aperture recording that the data returns over time and reconstructing a synthetic antenna in space or wherever you happen to be collecting from to generate the image. This actually helps space borne collection, the smaller the physical antenna in a synthetic aperture array, the sharper the resolution can be. A little counterintuitive, but if you think of it as painting a picture with a smaller brush you get the idea. W117L in addition to being linked to radar systems is of course the ancestor of the CORONA system, the GAMBIT and HEXAGON systems, and everything else we currently do in space. Its goal, however, was near real time capability. Later renamed SAMOS, the W117L program sought to return imagery in real time. It proved impractical at that time. Technology certainly was not there. QUILL becomes the first demonstration of a near real time capability.



By April of 1960 the potential for Synthetic Aperture Radar or SAR as an intelligence tool was displayed to the public. This is the front page of the Washington Post, it shows an image taken by an aircraft mounted ANUPD-1 Side Looking Radar of Washington D.C.

Now clearly this is not the best of images, but you can get an idea of what it's capable of. Even from this poor image you can see National Airport, you can get Hains point you can see that the urban sprawl of today is definitely lacking in the image. The intelligence potential is fairly clear here, and it was clear to the Washington Post reporter that wrote this article, he speculated in 1960 that the hardware involved in creating this image could be mounted on a spacecraft.

M9009 first image Aug 1960 M9035 launch May 1962

So taking us back to 1960, 51 years ago this month, discoverer 14 goes up beginning the era of intelligence collection from space. By summer of ’61, the deputy director of SAFSP Program A Colonel William King established a study group to look at other potential means of collecting intelligence from space. By Fall of 1961 they start looking at the possibility of launching a radar satellite: A proof of concept mission. The driving interest in this is not as a replacement for photographic intelligence, it’s to support the strategic air command with post strike analysis. Planners realized, especially in SAC, that in the event of a nuclear war, gathering photographic intelligence in a post strike environment would be somewhat challenging. Radar offered one potential work around. By November of ’62, the Director of the National Reconnaissance Office, Joseph Charyk, approves this approach. He likes the idea of an experiment, but he emphasized that it would be an experiment – and this is important in understanding where QUILL fits into the NRO’s history. Director Charyk states that the effort is to be strictly experimental in nature, and is not to be considered in any sense an operational prototype or the initial step in an operational system development. The Request For Proposal should make clear the experimental rather than the operational prototype or system nature of this effort. QUILL was an experiment. The inevitable question is, what happened after QUILL... it was an experiment it completed its mission and we moved on.

King assigned a young officer that would play a significant role in the rest of NRO’s early history, Major David Bradburn to direct the QUILL program. The program itself was not named QUILL this is Project or Program 40, P-40, the satellite’s name is QUILL. So P-40 and QUILL are used interchangeably you most commonly see it, if you see it, at all as QUILL. P-40 went on to become, arguably, the NRO’s most successful program. Historian, Robert Perry summarized its accomplishment and this is somewhat interesting, there are three historians that have looked at the history of QUILL so far—Robert Butterworth, Robert Perry and myself. When three historians look at a program and all come to roughly the same conclusion it's either a very strong conclusion or somebody is not doing their job. I like to think this is a case of everybody coming to the same conclusion for good reasons. Perry summarized it as "In the first twenty years of the reconnaissance satellite program 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." Now you've got to water that down when you realize that QUILL flew one and only one time. It's either 100% success or 100% failure. Sometimes being a one shot program helps.

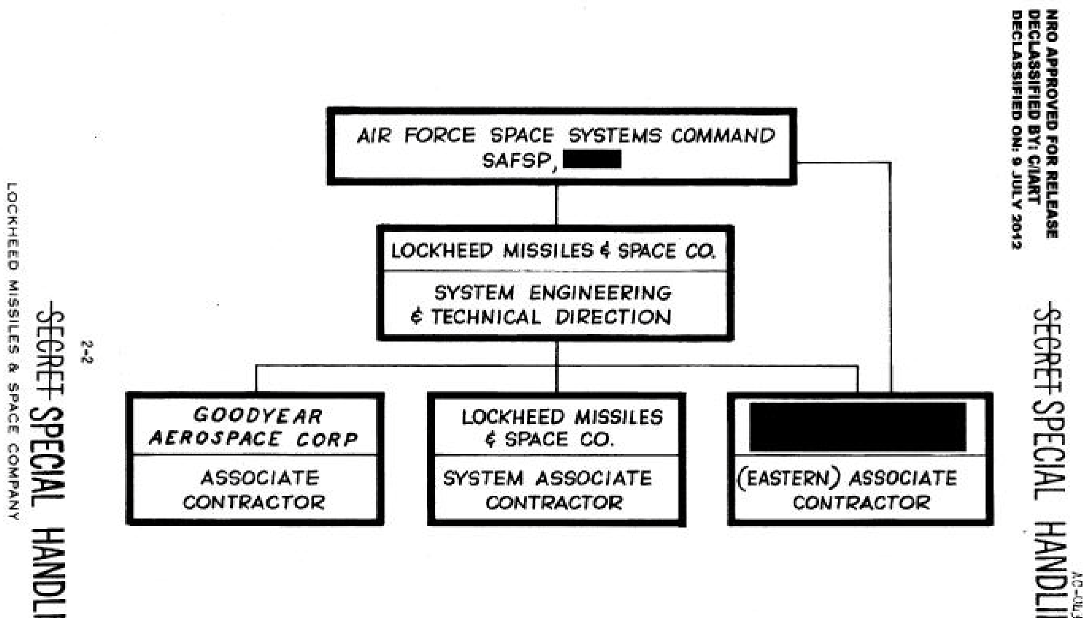


Figure 1.2.1.1 Program Management

The contact actually called for two identical mission vehicles designated as missions 2355 and 2356. The first launch was scheduled for April of 1964. The contact also called for the preparation of a third payload that did not designate a launch vehicle for it. The idea was two missions, possibly three. And this slide indicates the program structure.

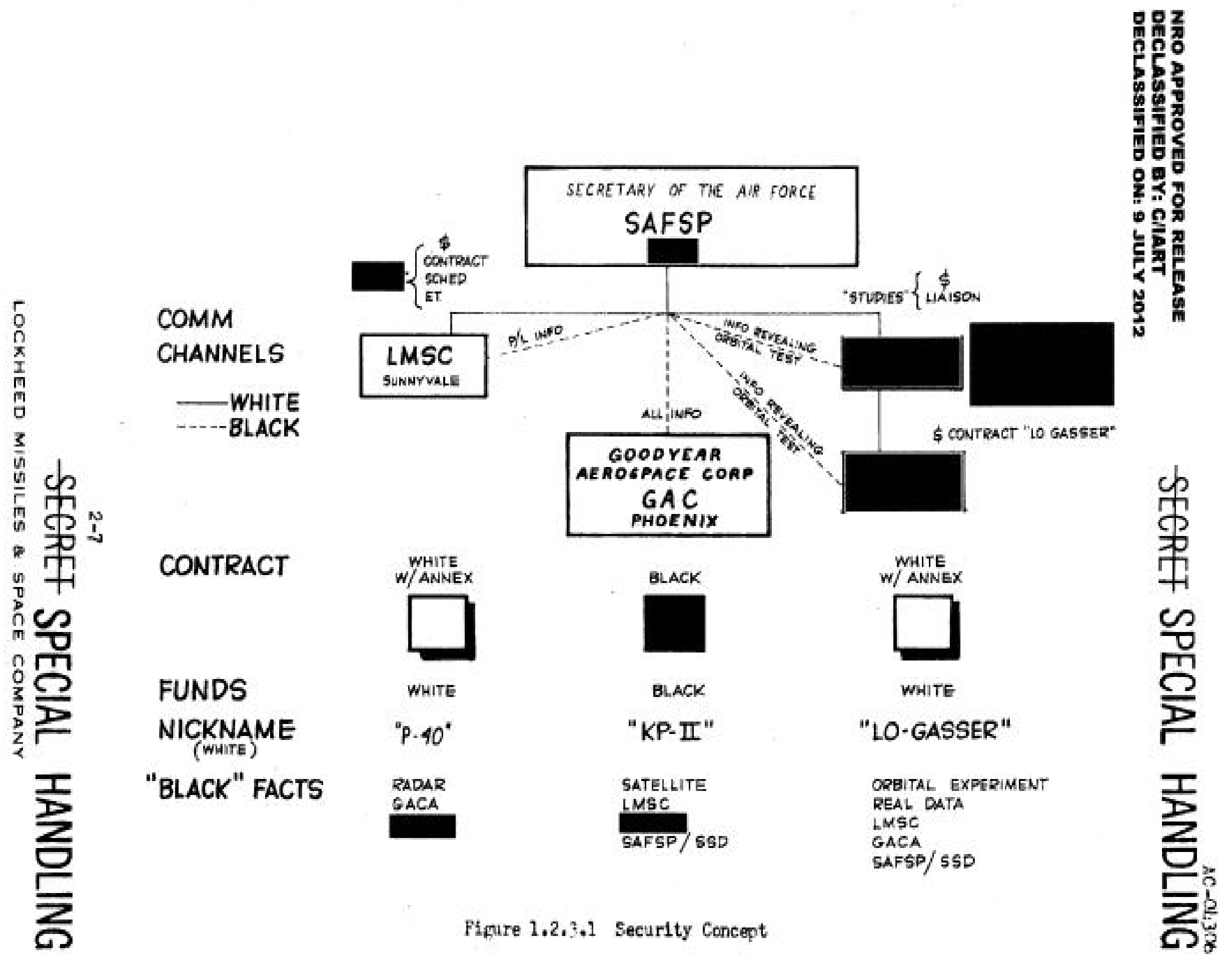


Figure 1.2.3.1 Security Concept

With a fairly complicated security plan to protect QUILL’s existence and this has remained remarkably solid to this day. There was very little about QUILL that could be seen until the “Fact of” QUILL was declassified some time ago now. The Air Force actually acknowledged programs called P-40 and Logasser. [They] could be seen in the unclassified world, but no information about it.

When P-40 came up for review to Secretary of Defense McNamara he called in his Senior Technical Advisor, Dr. Eugene Fubini, who immediately had a serious problem with the program. He noted that the budget for the experiment appeared to be charging roughly five times the cost of the radar system he assumed it was based upon. He saw it as based upon an existing APS-73 radar unit. In fact it was based upon this aircraft the RF-4C then beginning to enter serial production in 1964 to support the Air Force's need for an airborne reconnaissance vehicle that could use side looking radar, Synthetic Aperture Radar. GE was, no Goodyear, excuse me, was developing a AN/UPQ-102 Doppler system. What the NRO's engineers did was take this state of the art Air Force radar, then under development, and find a way to space rate it. They pulled off the unnecessary components which provide stabilization, fine focus, could control for an operational air breather, stripped it to the bones, space rated the rest and then that became the KP-II radar system that would fly on QUILL. From the beginning, Bradburn as the program director focused P-40 on demonstrating orbital functionality of radar. Lockheed in supporting that mission established an early goal of 50 foot resolution in both dimensions azimuth (across track) and slant range (along track) resolution. 50 feet. Secondary missions were simply to: Prove the technology, see what the limitations were, find out how the vehicle actually affected collections in space. But the primary goal is simply proof-of-concept.

The experiment sought to answer only two questions. Could the system achieve the desired resolution in the Azimuth plane? (Not the slant range plane just the one plane), and did atmospheric phenomena—weather, clouds and height, interference of any kind—degrade performance? So the operational capabilities like the swath selection, fine resolution, along track were not subject to study. They realized that most of these could be simple engineering developments off the parent vehicle. This is low-ball, off-the-shelf, can-we or can't-we do it, proof-of-concept mission.

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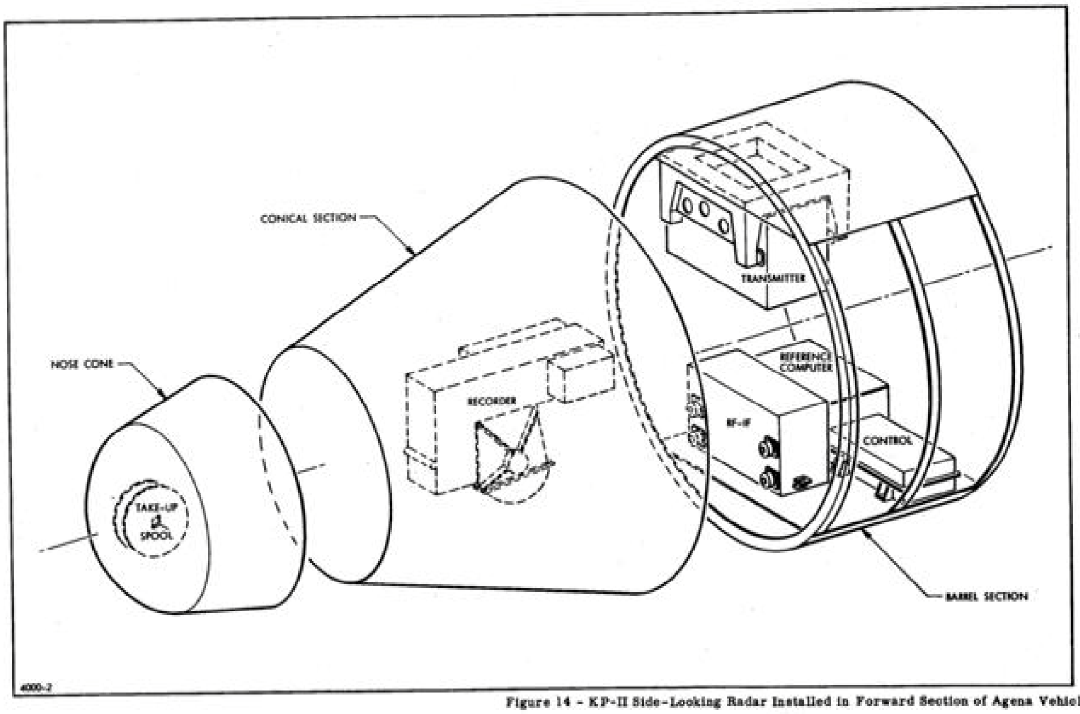

Figure 14 - KP-II Side-Looking Radar Installed in Forward Section of Agena Vehicle

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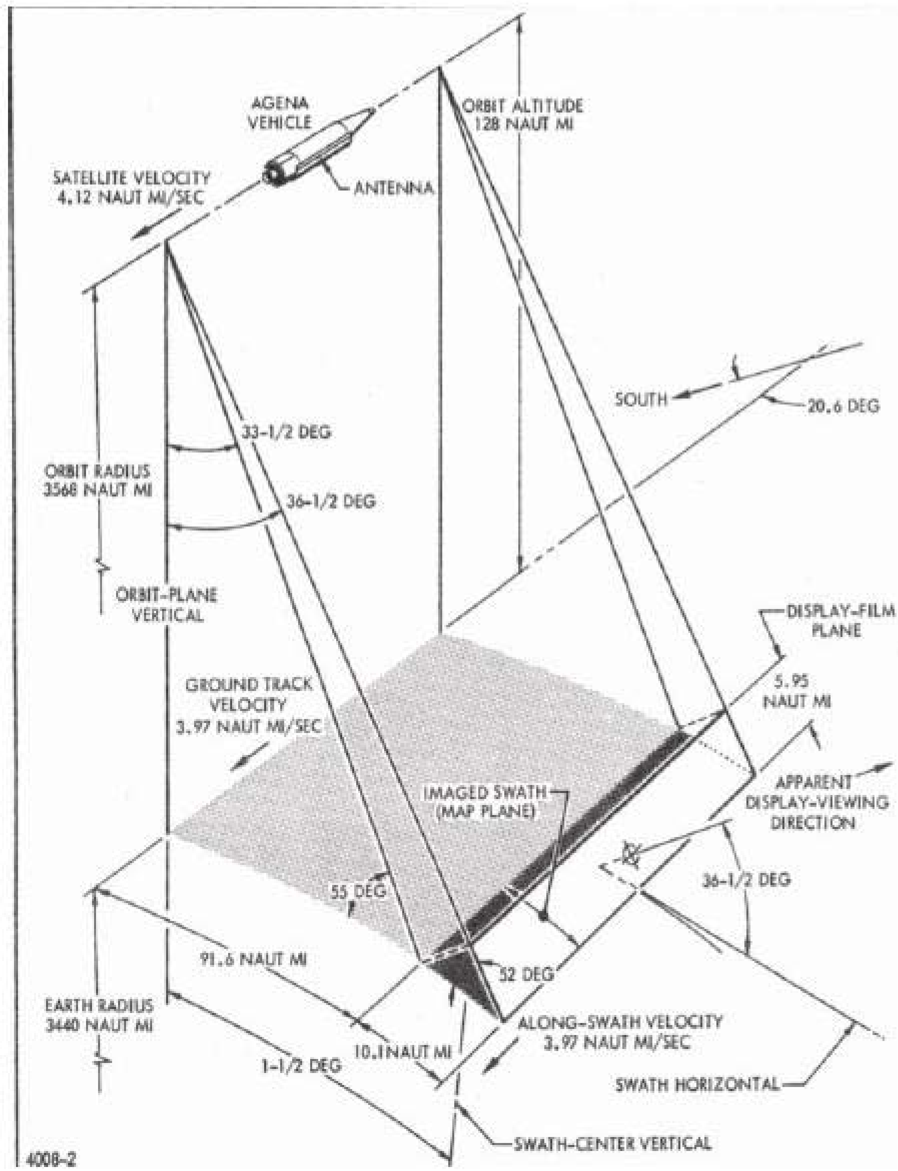
The radar of course is only one component that's available to SAFSP from an off-the-shelf radar system. The other component is also available off-the-shelf, the CORONA system. The big problem when W117L faced in near real time intelligence was sending data to Earth. It could not be stored due to a lack of real electronic storage information, it could not be sent down with high bandwidth… relays. What the engineers do is combine some of the W117L approaches that did not work, CORONA's successful approaches, and the very nature of side look radar. The data returns from the radar unit are inherently digital, but this is an analog era. What they do is take the readout, the returns from the radar system, physically display it on an oscilloscope, in orbit, then a film passes over the oscilloscope and captures the oscilloscope readout on wet film. The wet film is returned to earth for processing just like a CORONA mission. At the same time the feed, the input to the oscilloscope, is relayed in real time to one of two ground stations inside CONUS. On the ground the same oscilloscope display picks up exactly the same data, a duplicate recorder produces a film image and now we have an analog film to process. It's an elegant solution, but doing something with the resulting film is a challenge in and of itself.

QUILL's experimental mission would last only 96 hours as proof-of-concept it did not have to be a long duration mission. During the 96 hour mission the KP-II radar system would operate no more than five minutes in each orbit, for no more than three orbits in succession, and the batteries powering this system, only three of them, could provide a maximum of 80 minutes of collection for the entire mission. This is a low ball mission from beginning to end, but this duration is not all that different from the early CORONA missions.



And so the complex geometry and terminology involved in radar, of course the terminology has gone on to evolve, I'm sure we have a few radar folks here in the auditorium, maybe more listening in, they will go on about this technology/terminology if you're interested, but once again the goal of this program was simply to achieve resolution in the slant range or 90 degrees from the actual vehicle track. The antenna is aimed physically by the aircraft, the parent Agena; it's locked in a position roughly 35 degrees off the track, to the right of the vehicle track and scans that image. There is no capability to select the swath, width excuse me. There is no real fine aiming capability. The idea is to simply take a picture and see what it looks like.

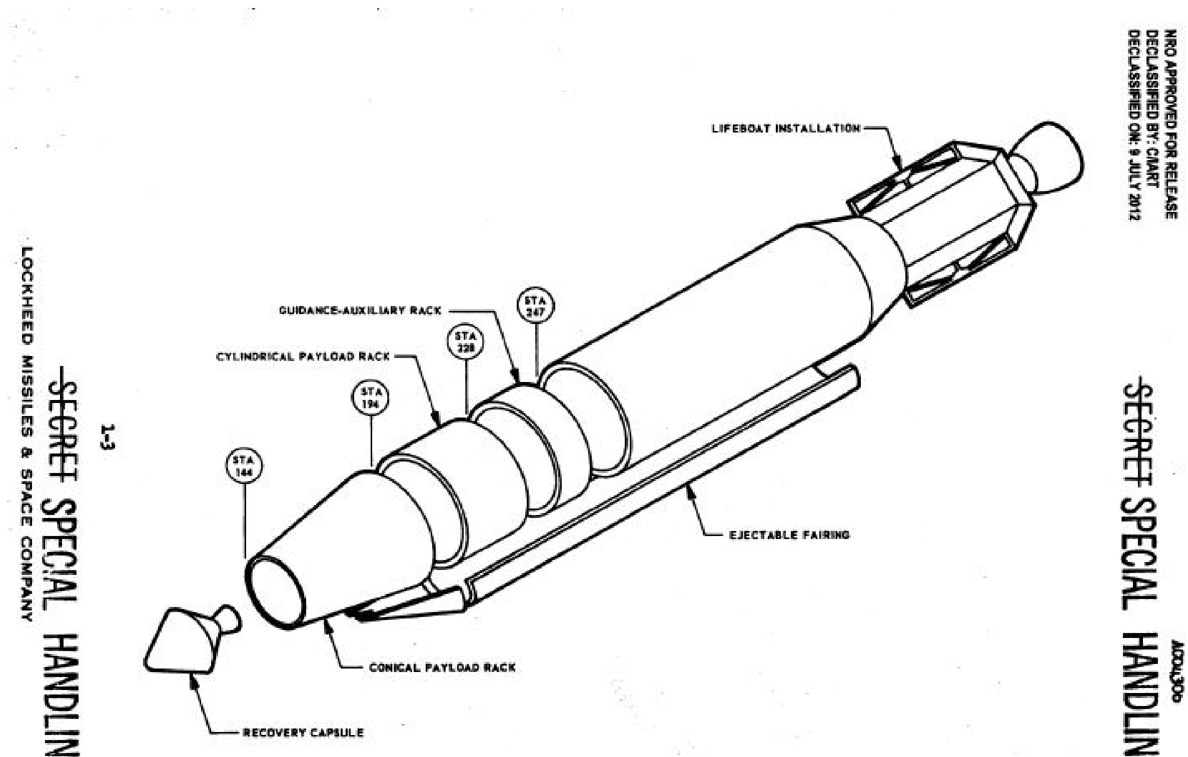
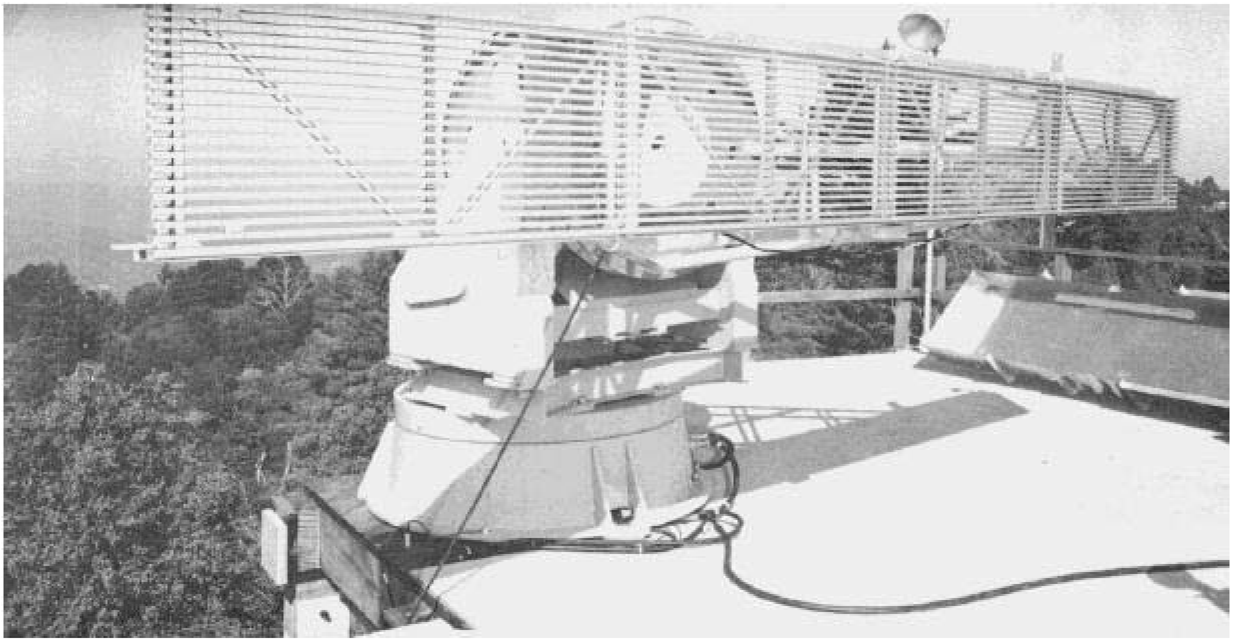


Figure 2.1.1.1 - Major SS/A Components

Physically the QUILL vehicle displayed its origins, the only way to tell QUILL from a CORONA launch is by this eject-able fairing along one side of the aircraft, actually spacecraft excuse me, that actually covered the antenna. There are very few pictures of QUILL remaining and the only way to tell it's QUILL is by this odd shaped fairing that's on one side of the spacecraft. It's also very tiny although it measures, the antenna 15 foot by 2 foot. The antenna protrudes only 2.5 inches from the surface of the vehicle itself at the closest approach. So it's fairly small discrete bump if you're seeing a long range photograph. Seeing an actual photograph of the QUILL vehicle where you can tell it is QUILL is rather rare.



Demonstrating the off-the-shelf nature of this, this is the QUILL antenna. 15 foot by 2 foot, built at Lockheed Antenna Lab from existing stock. If you can imagine the NRO today calling up somebody and saying “build something from what you’ve got in the warehouse”, that’s what they did here.

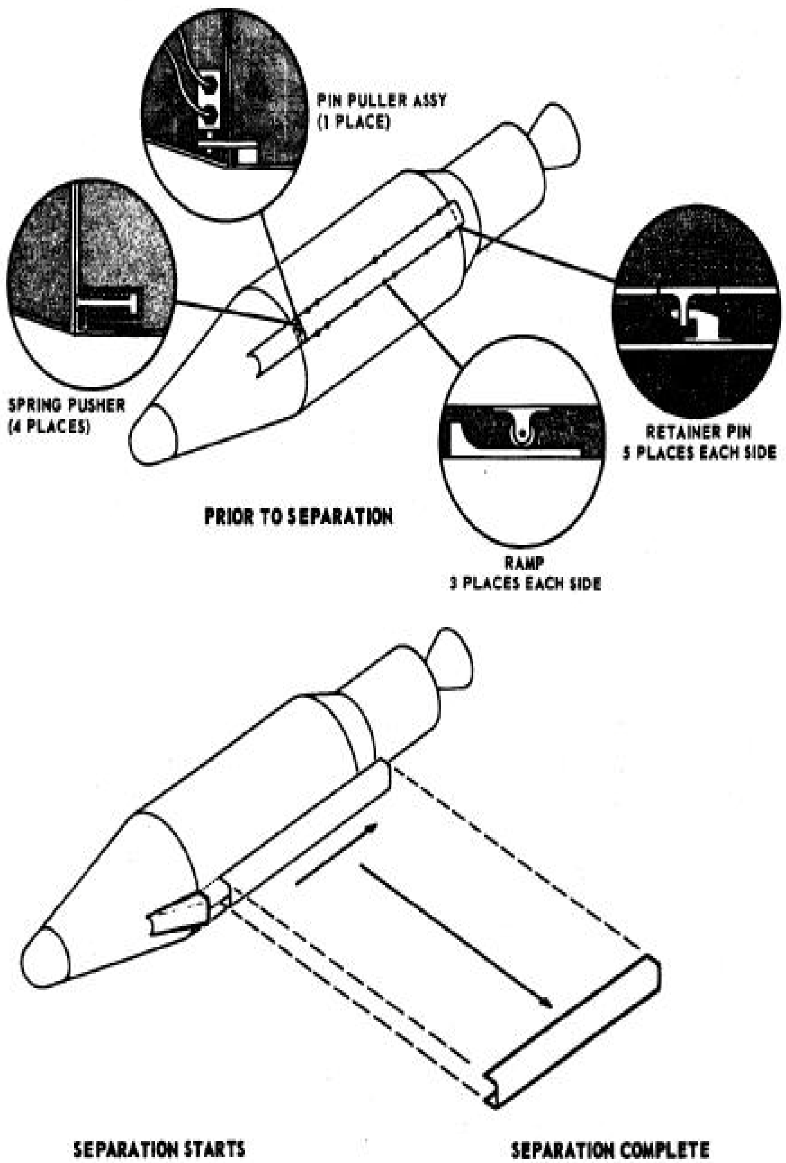
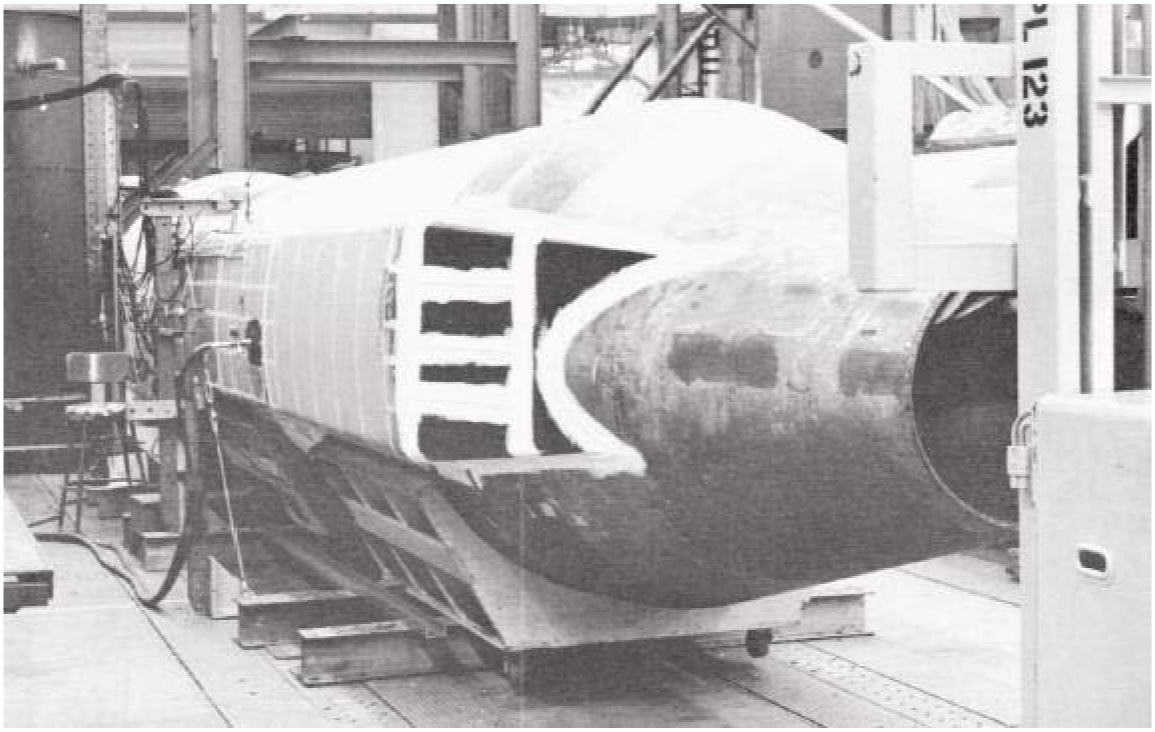


Figure 2.1.1.6 Vehicle Fairing Separation

The fairing itself would be ejected once the Agena got into orbit, exposing the radar. The radar antenna was simply mounted on a sliding track, one fixed mount, three sliding to account for thermal stress on the vehicle. Very simple engineering, but remarkably successful. And again, the radar antenna itself was fixed to image 35 degrees to the right of the vehicle track.



Here we have one of those rare images of the QUILL vehicle displaying the fairing. Again, there are very few images of this that survive. The records are essentially non-existent. So it’s nice to have a few remainders, a plug for records mangers here at the NRO, this is the reason we want to work very closely with them. It’s to preserve what we’ve done for future study, future lessons, there is not a lot left of QUILL. So this is a great exercise in both records management reconstructing what little survives and for the historians to understand what it all means at this point.

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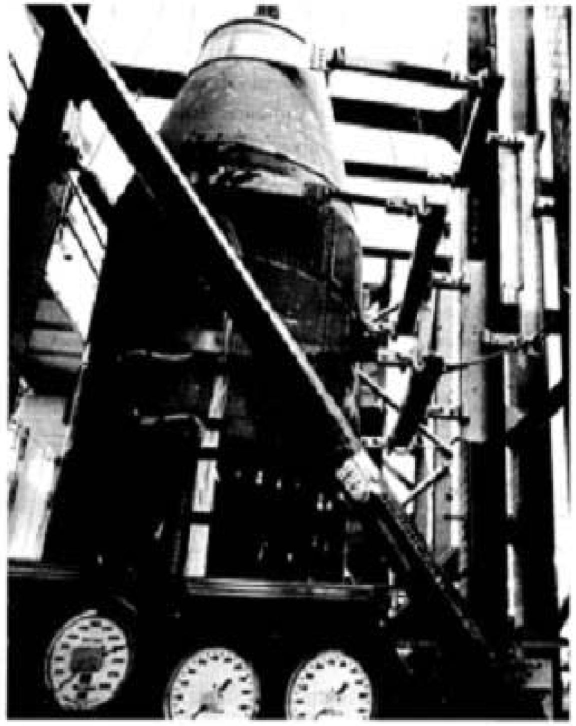

Figure 2.1.1.8 STATIC LOAD TEST

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This is another of those surviving pictures all from the final reports from the system testing of the QUILL vehicle prior to launch. The development of the QUILL vehicle was surprisingly smooth, although scheduled for an April launch it only slipped until December of the same year, 8 months. This is particularly remarkable because the schedule was not a real issue, the emphasis was on mission success not on meeting any of the deadlines, but they still met the deadlines with remarkable success.

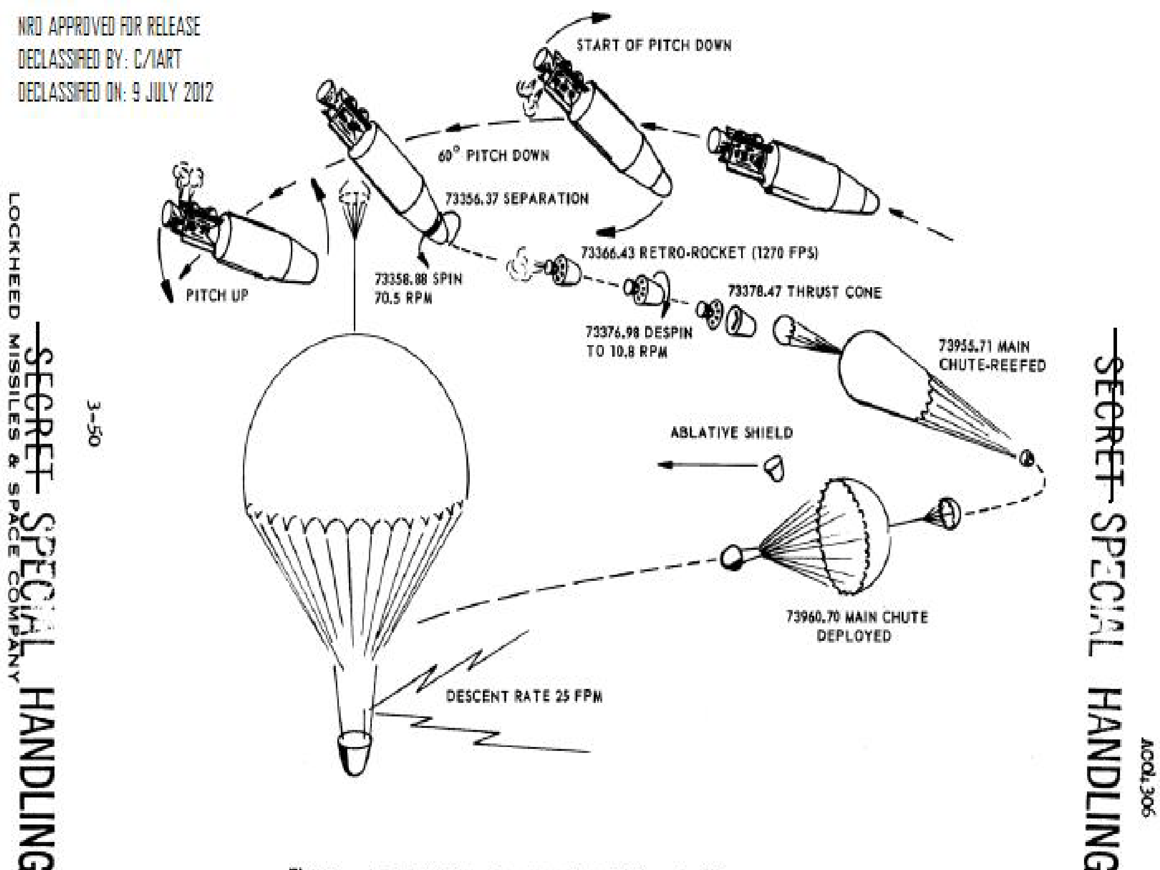


Figure 2.3.2.10.3 Recovery Event Time Profile

The mission would progress along tried and true CORONA systems. In fact this is one of the reasons that QUILL has successfully remained obscure from much of the public to this day. After launch it was almost impossible to discern QUILL operations from CORONA operations: The same mission profile applied, the same ground stations were working, same launch vehicles. There just wasn’t that much to differentiate this from any other mission. The one factor that is different from CORONA is the limiting factor. With CORONA its film, with QUILL its battery power. In fact, because of the near real time capability, once the film was ejected, the QUILL program or QUILL mission can continue and it does so.

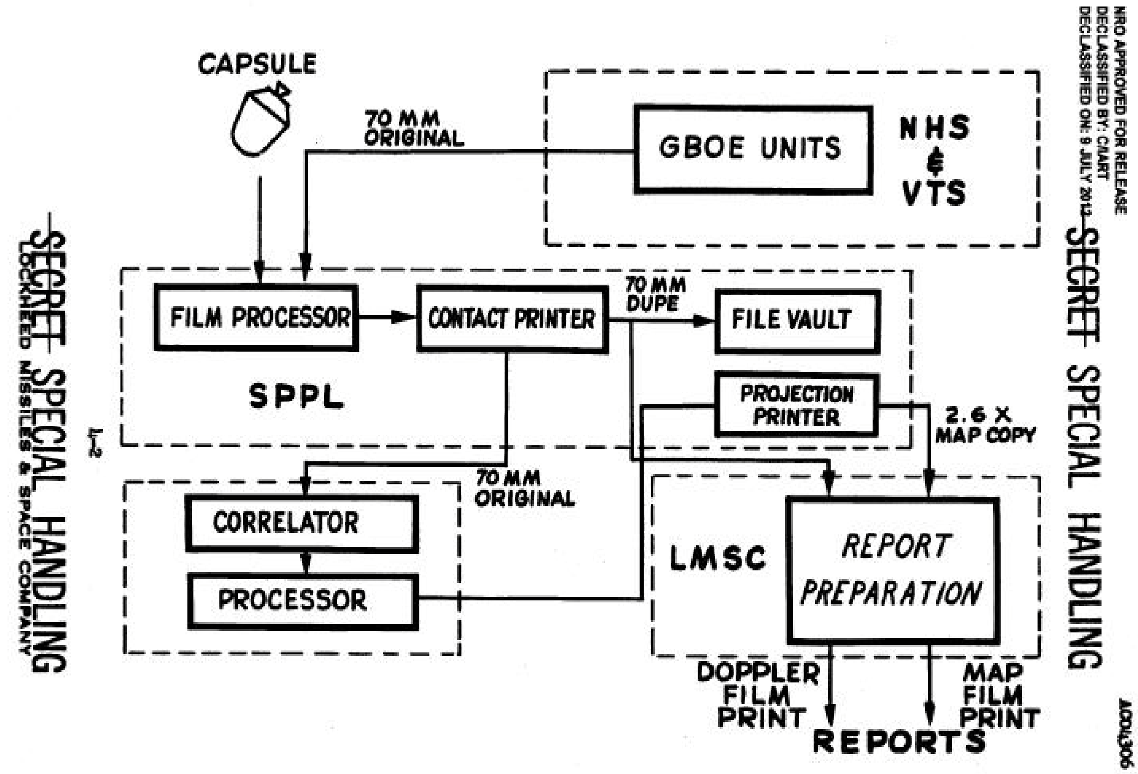
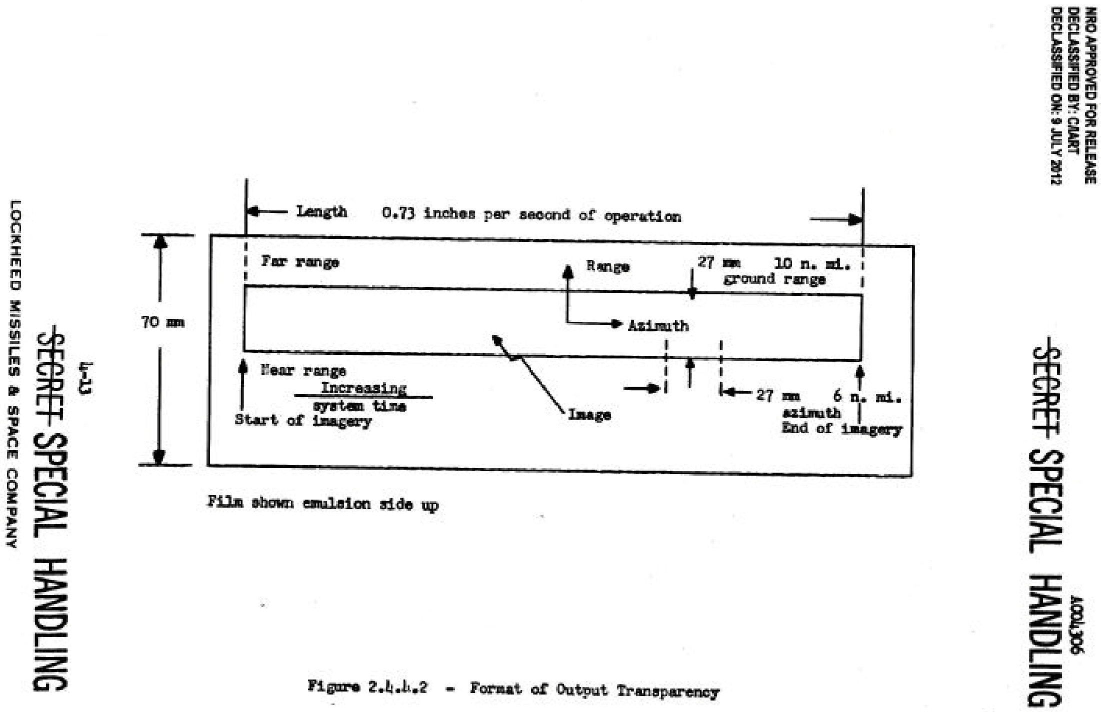
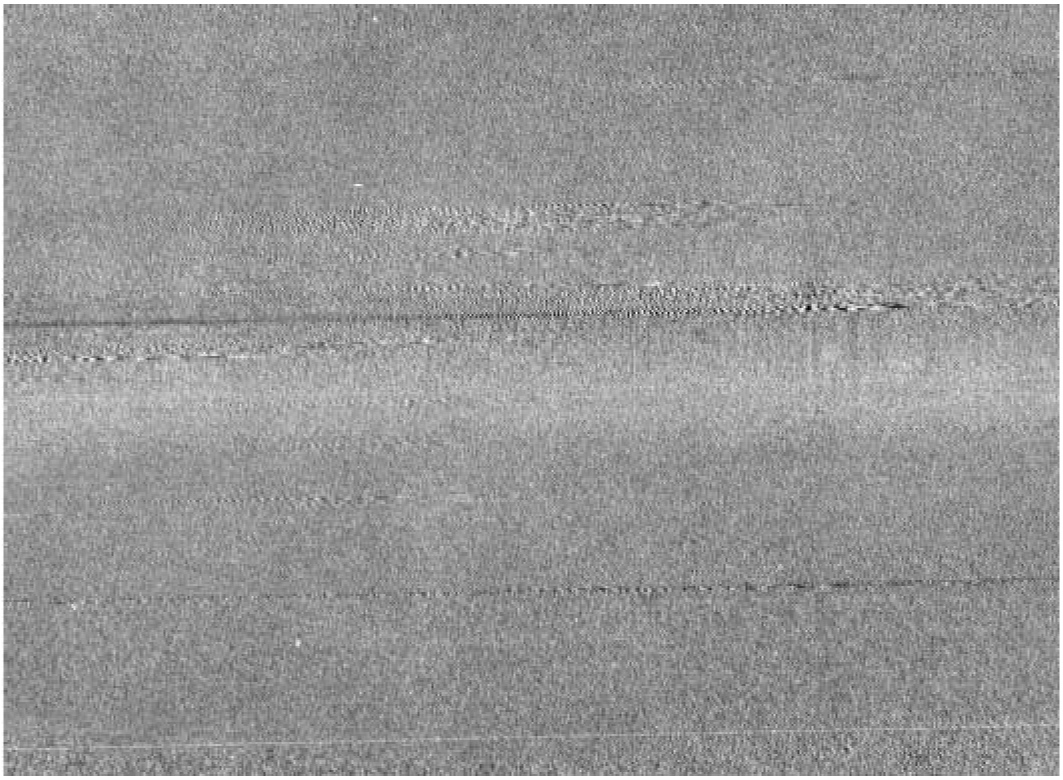


Figure 2.4.1.1 - Data Flow-Block Diagram

Whether the film was retuned physically to earth, or created at one of the ground stations from the direct readouts, the end of the mission would have three different sets of film: One complete set of film from the vehicle and two partial sets of film from the ground stations capturing the data. What happened next was identical regardless of the source of film. It would be processed, duplicated, run through an optical computer, produced in hard copy and analyzed. Unfortunately, in each step of the process the initial resolution was lost, so that by the time it comes to an analyst's desk the actual product is seriously degraded not by the collector, but by the process and technology at the time.

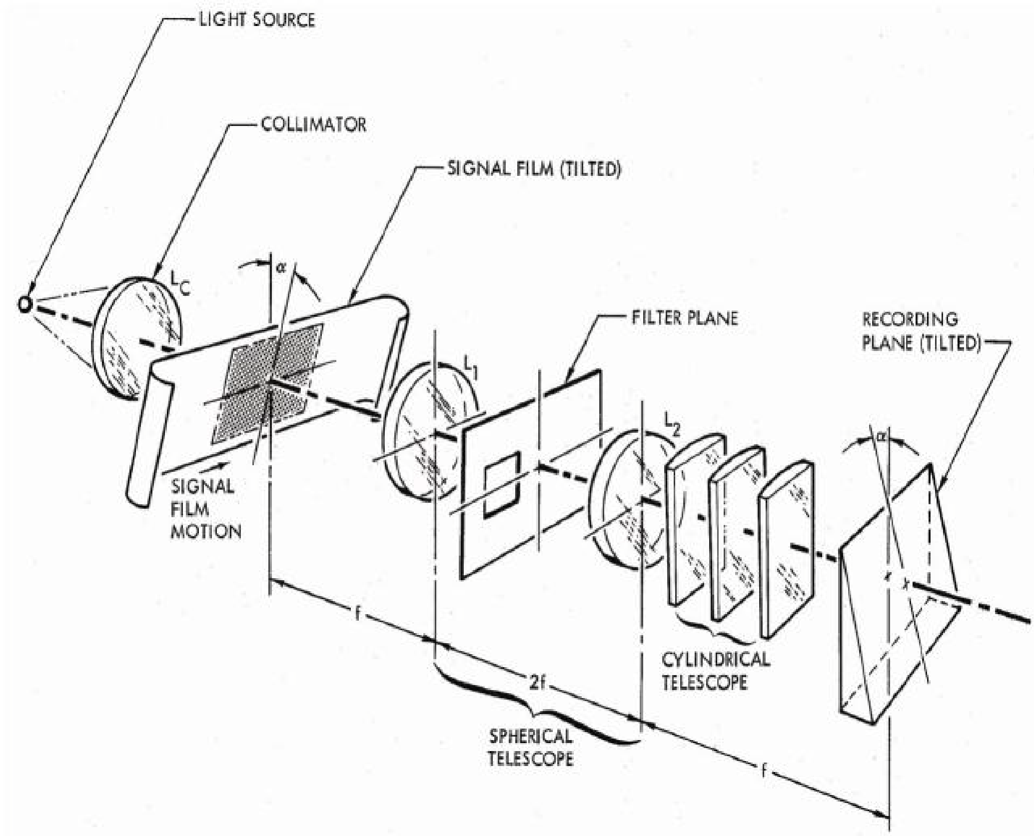


The output on film is literally a film image it is captured in an ongoing strip, the length of the exposure, the length of the target run for the radar and the width of the imaged area. Identical film recorders capture this data, again one on the spacecraft, one in either of the two ground stations supporting it which were Vandenberg AFB and New Boston, New Hampshire. All of the images captured by QUILL are domestic, that's one reason you will not see them on the publication sitting on the side table there-- there simply wasn't time to get the domestic use paperwork through. There was a reason why it was domestic imagery. This is 1964, we're still learning what the limits are for space based reconnaissance. While photography is passive, in ELINT its passive, were talking about an active scan now, we are actively penetrating denied territory with something, in this case a radar beam to capture data. So the question was is this or is this not a hostile act? What will the reaction be? The decision was made, because this was not an active mission, but simply a proof-of-concept, to image only over the continental United States. That also facilitated the near real time capability. W117L's big problem with real time, besides the technological limits, was the lack of a data relay satellite. The W117L approach would have had to directly relay to a ground station in view which would mean the signal could be potentially intercepted by the hostile power that you are trying to image: Serious security ramifications there. This is strictly over CONUS collection, strictly for experimental purposes. And even if somebody had managed to intercept the signal, that's what they'd get. That's an actual image of the film.



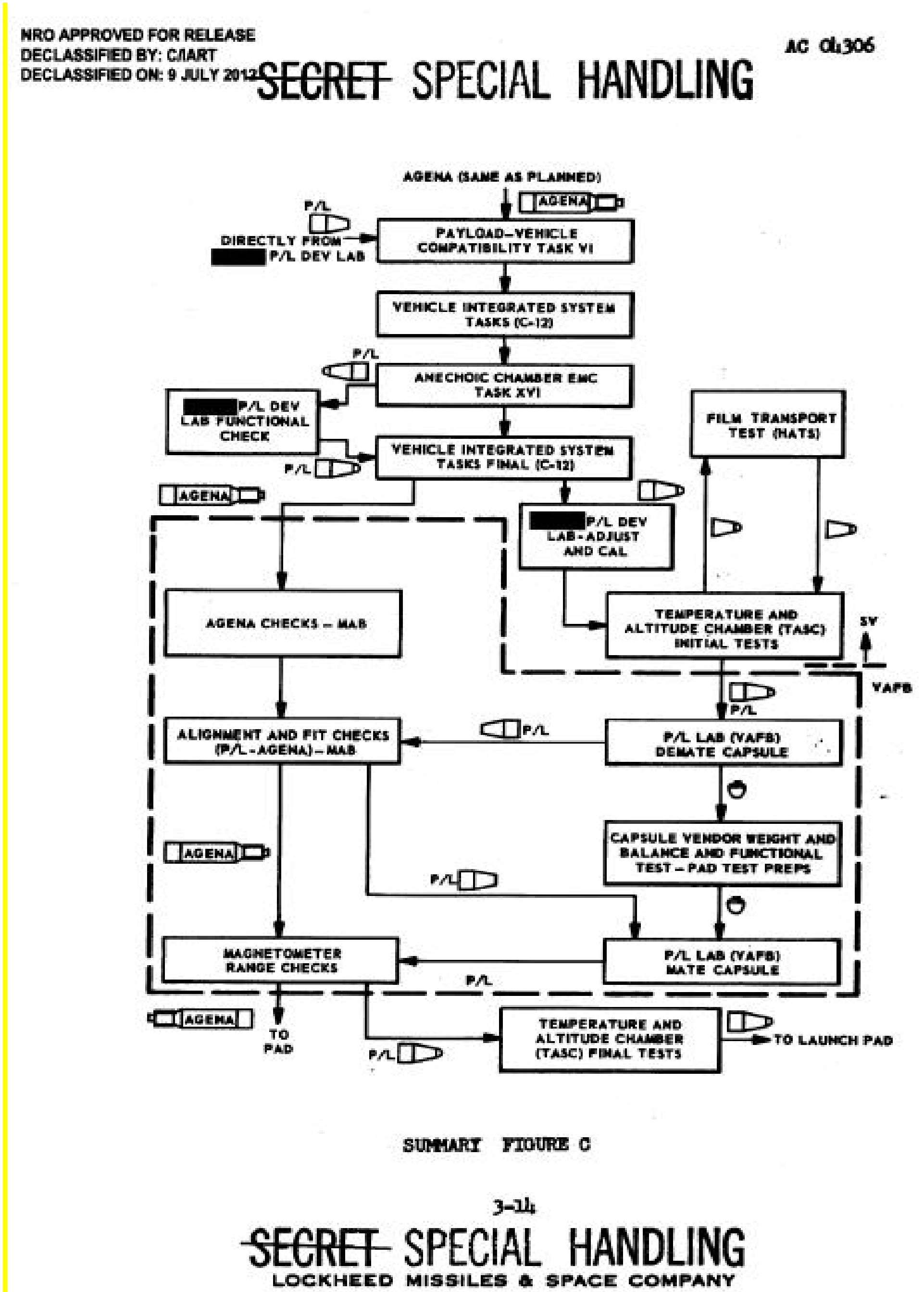
The film by any of these systems is just white noise. Trying to analyze this image would be an interesting challenge to say the least. This is pre-digital era, there are no digital computers to decipher this information. To decode it a revolutionary technology is deployed, and this technology was white world.

The University of Michigan had openly been pursuing this technology for some time. Again, that 1960 slide of the Washington Post cover was produced by exactly the same technology. What you do is take a film transparency that looks exactly like this and run it through the Precision Optical Processor: An optical computer. This is the beginning of the science of Holography, optical computing; this really forwarded the mathematics behind the Fourier transforms. All this comes into play as a workaround for the lack of digital computing. They find a way to compute this information, transform it back into useful information using optics.



And that's what the Precision Optical Processor, the POP, actually does inside it: Simply an array of lenses, prisms, a focal plane and lasers for illumination sources. By running the transparency through this, you can expose another set of film, get a duplicate and analyze it.

A big part of QUILL's success was the CORONA program that it built off of, it follows exactly the same preparations-- launch prep, checkout processes—and it in fact fit into the system very successfully to protect the existence of QUILL.



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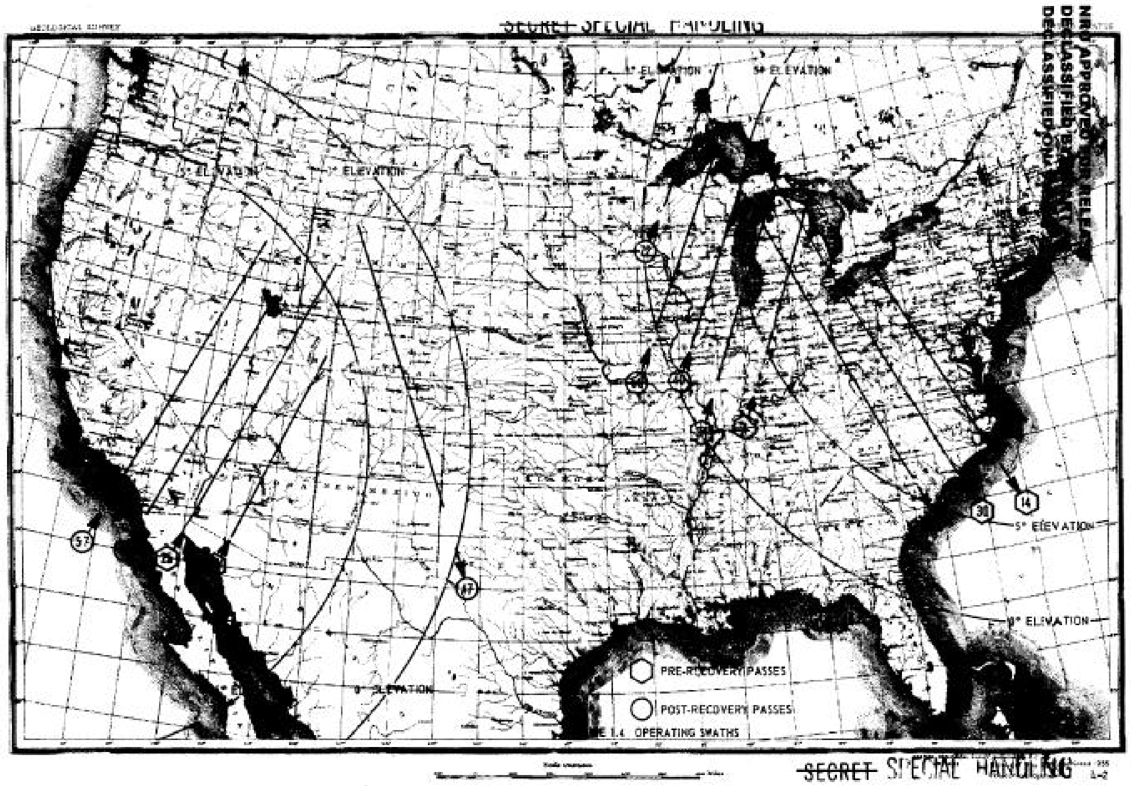
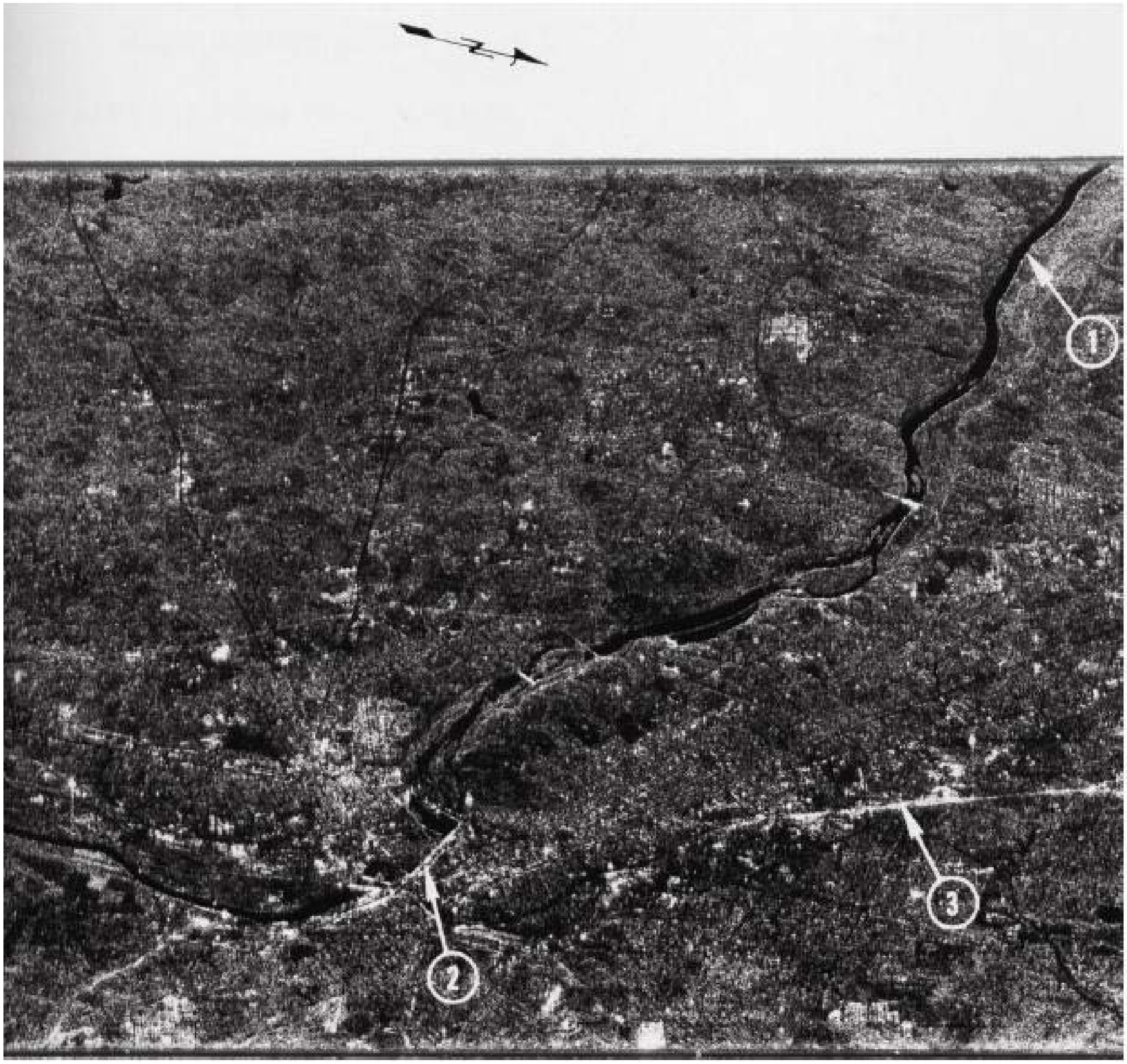
A lot of the Corona personnel, that support the launch are never aware that they are supporting an entirely different program. Bradburn had stressed that a successful flight was far more important than any schedule, again QUILL launched only 8 months after its initial target date.11:08 PST, 21 December 1964, it launches off of Vandenberg and begins returning data just a few hours later.

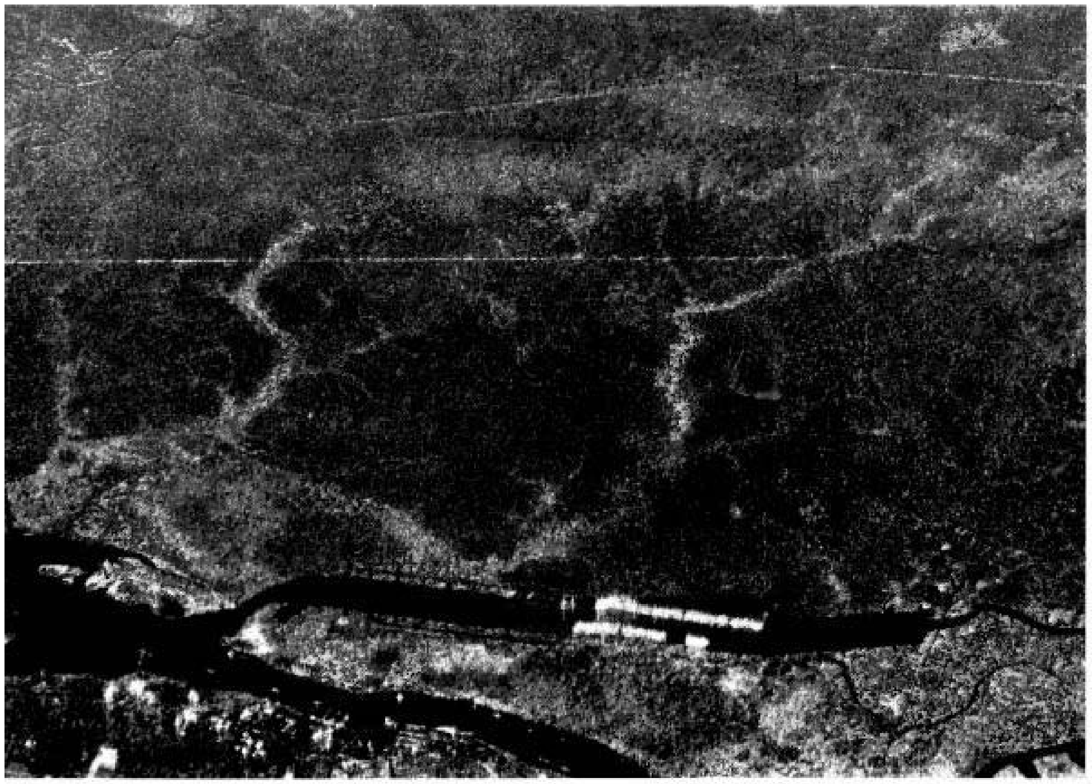


Right on target, QUILL’s batteries run out of power on orbit 72 and 73, 26 December 1964. The radar operated only 14 times in orbit. It imaged large swaths of the U.S. roughly 80,000 square miles and returns useful imagery of about 80% of that area. After seven of its radar passes it returns the film to earth, operated for seven more passes on a direct read-out mode only, and those later seven passes were to experiment with the system little bit further—adjust settings, see what you can do with the ground processing with the radar, find out what exactly the useful parameters of this system were, and they turned out to be truly remarkable. The final target that Bradburn had established, again only in the one dimension, was ten feet of resolution. The system achieved 7.5 feet of resolution. That is the theoretical maximum for that antenna. You can theoretically obtain one-half the size of the antenna, a 15 foot antenna, it got 7.5 foot of resolution. Absolutely remarkable. It proves the concept is valid, it proves you can successfully return radar imagery from space in real time yet, and find some useful intelligence information out of it. The system itself re-entered… where is the date?... 27-28 December somewhere in that time frame, just a few days later. A very short mission but highly successful.

The actual take. Remember what the data transparency looked like, just white noise. When it's run through a Precision Optical Processor, that's what you get.



And to understand what this really is, again a records keeping problem, we do not have any of the raw data to look at, what we've got… this is a good example, this is a scan of an 8x10 glossy photo that's in the final mission report. That's the form of the surviving imagery. In the process of taking from oscilloscope, which is a downgrade of the actual digital return, return to film, you lose some signal, from film to Precision Optical Processor, you lose some signal, from POP to the actual print you lose some signal and you end up with something like this. This is a reproduction of a reproduction. But still you can get an idea of the intelligence potential. This is Richmond, and you can see the urban area, you can pick out the highways, the bridges, the railroad track is discernable, if you look closely you can see the street grid. This is a degraded image. The real one, 7.5 foot in the one dimension you can see remarkable things in this imagery. As a proof of concept this is remarkable, especially when you remember that the first Discoverer, well CORONA mission excuse me, can't remember which environment I'm speaking in today. The first CORONA mission only achieved 40 foot resolution, this is 7.5, all weather day-night.



Here is another good example. This is the James River reserve fleet; the ships in the reserve fleet provide a remarkably strong return. Again these are all degraded images, but here's a blow up, indicating just the strength of the return.

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FIGURE 1.6.9(b) CLOSEUP OF MOTHBALL FLEET

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Even this nth generation hard copy scan, you get the idea that you can discern at a glance individual ships at least. In the imagery that is retained in the final report there are a couple of really interesting images. Operating off the West coast, QUILL caught a couple of vessels underway in the Pacific. What's remarkable about that is, that [with] QUILL imagery, because of its resolution, you could calculate the ship's rough size, its approximate shape, you can discern its wake (so speed and course). Day-night, all weather.

Here is a raw image from QUILL. One of the problems that QUILL faced, actually an opportunity, was bad weather over the Pacific for much of its operational lifespan. Rain squalls, limited visibility. You can still see, in this un-retouched photo, dominant wave patterns, you can get an idea for some of the weather interference, but when you process the information through the POP, adjust the settings a little bit you get a refined image.

The arrows here indicate dense rain squalls, visibility in those rain squalls was under ¼ of a mile. But you can still discern dominant wave patterns; you can see the surf lines off Point Reyes. You can see how the surf curves around the Point. This is just an experiment, the potential here is truly remarkable for 1964. No imagery satellite could have penetrated that cloud cover. ¼ mile of visibility in the storms and you can still discern useful information.

The problem is that QUILL succeeded in its first mission, so what do you do next? Contractors immediately recommend a second launch to follow in the fall 1965 gather more information, but Program A director, by then Major General Robert Greer, did not agree with this conclusion. The first mission had accomplished all of the program goals. The DNRO, Brockway McMillan, agreed with the Program A director in this. Project 40 had completed its mission. QUILL had proved successful, it had demonstrated the capability and operational need was simply unapparent at that point in time. So the decision was reached to continue the study on the ground, but no further launches. In 1972 a report, an NRO position paper, explains, I quote: " It was concluded that no further satellite experiments as such should be conducted; instead efforts should be made to define precisely the system application desired, and then the development of the actual system should proceed." We're looking in 1972 in some sort of operational mission for radar, but it's going to take some time. Going on… "The system application studies, intended to be conducted in parallel with the engineering demonstration, were not decisively concluded." And there's the historian's question mark: not decisive? Looks pretty decisive if you look at the imagery. No agreement could be reached in 1964, 1965 mid to late 60's what you could do with this information that couldn't do with photography ignoring the day-night, all weather aspects.

There are several reasons for this, some are institutional, Program A [vs]. Program B interaction. The fact that this is largely geared toward what at the time was a SAC mission, post strike analysis. SAC is a strong defender of pursuing this system. For post strike analysis it's a unique capability, but while championing its continued development, they did not provide funding, they did not really pursue it and even inside Program A some argued against SAR's potential utility. The problem we are facing in the 1960's is Vietnam. Funding is becoming increasingly austere; the resources simply are not there. DNRO Flax is confronting internal problems in the NRO, reorganizing/cleaning up what his predecessor had done. So the QUILL program is cancelled, remaining funds in the program are diverted or reassigned to the management reserve. The program closes out with a surplus, after a complete mission success. The hardware itself is returned into the CORONA program to be reutilized, the unique QUILL aspects are destroyed. There is an effort some years later to go back and find some QUILL artifacts to prepare them for display in the Smithsonian. When the time came, when they undertook that effort, they discovered that nothing survived. So all we have to show for the QUILL program is the final reports, a handful of scattered references, [and] the histories. Despite that, it's a remarkable achievement for the NRO. This is 1964 when satellite photography is still a new and highly classified science. And here we are using radar. Day and night, all weather, a proof-of-concept with off-the-shelf information, off-the-shelf resources that achieved 7.5 foot of resolution. Now commercial today [is] 1-2 meters. This compares in one dimension to what commercial is doing. The engineers, in 1964, inside the NRO simply assumed that they would be capable of achieving similar resolution in the other dimension if they so chose. It would just increase the funding requirements and increases the engineering complexity.

This is a program well ahead of its time, it starts asking the engineering questions, asking the analytical questions and training the analysts. That's one of the reasons that there wasn't a lot of hue and cry from the imagery analysts to get a radar system. If you're used to looking at CORONA, which by 1964, is returning some good solid resolution images. And then you look at this stuff, it does not compare. Until you start to look at the day-night, all weather aspects and you begin, what we are all aware of here, to see what radar can really do when you start processing the information. They didn't have the processors yet, they didn't have the analytical background yet. So it becomes an engineering challenge and a challenge in opening analysts' eyes to the capabilities, the capacities that are in this new technology.