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Designing the United States' Initial "Deep-Space Networks:" Choices for the Pioneer Lunar-Probe Attempts of 1958-59

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Abstract

To support the series of early Pioneer lunar-probe attempts by the US Air Force and US Army, in 1958-59, Ramo-Wooldridge's Space Technology Laboratories (STL) and Caltech's Jet Propulsion Laboratory (JPL) designed two separate networks of ground stations. Because the probes were authorized as a potential quick means of restoring international prestige to the United States, after the Soviet Union's successful orbiting of *Sputnik 1*, and thus were all scheduled to be launched within a year of authorization, both networks had to be installed on a crash basis. The differences between these two initial networks–in terms of antenna design, operating frequency, and location–are described, and it is shown how the extra months afforded to JPL (due to the later launches of the Army probes) allowed its engineers to design and install the first elements of a system that evolved within a few years into NASA's Deep Space Network.

1. Authorization of the Pioneer Lunar Probe attempts

On March 27, 1958, the Eisenhower Administration, through the Department of Defense's new Advanced Research Projects Agency, authorized a program (shortly to be called Pioneer) of five lunar-probe attempts. Three were to be done by the Air Force and two were to be done by the Army, and all were to be conducted within a year. Although the Administration publicly characterized the program as a scientific project [1], its major impetus was a desire by many, inside and outside the government, to find some quick means of restoring international prestige to the United States, after the Soviet Union's successful orbiting of Sputnik 1 had shattered a widely-held perception of American technological superiority. For example, at a meeting of the President's Science Advisory Committee (PSAC) on February 17, it was announced that the country would attempt a lunar mission with the objectives of "a. Making contact of some type with the moon as soon as possible, but with the limitation, b. That the contact be of a type such that the public can admire it." With these goals in mind, PSAC stated that the most significant experiment on an initial lunar probe should be "some kind of visual reconnaissance," e.g., a picture of the back side of the Moon [2].

The probes authorized were based on two proposals, made earlier by Ramo-Wooldridge's Space Technology Laboratories (STL) and Caltech's Jet Propulsion Laboratory (JPL), located, respectively, in Los Angeles and Pasadena, California. JPL's "Project Red Socks" proposal, presented to the Army, the Secretary of Defense, and the forerunner of PSAC, in late October, 1957, called for a flyby mission, launched by a combination of a Jupiter IRBM and a cluster of upper stages used earlier in a reentry test program [3]. STL's "Project Baker" proposal, made to the Air Force in late January, 1958, called for an impact mission (later changed to an orbiter mission) to be launched by a combination of a Thor IRBM and Vanguard upper stages [4]. The ARPA authorization of March 27 called for the Army Ballistic Missile Agency and the Air Force Ballistic Missile Division to supply the launch vehicles. These agencies, in turn, enlisted the aid of JPL and STL to design and develop not only the probes, but also the networks of ground-support stations that would be needed to communicate with the spacecraft, and to determine their actual trajectories. The design and installation of these networks is the focus of this paper.

2. The ideal network of ground-support stations

An ideal network for supporting space probes would consist of three principal stations, as a consideration of the apparent motion of such probes will show. During the initial injection phase, imme-

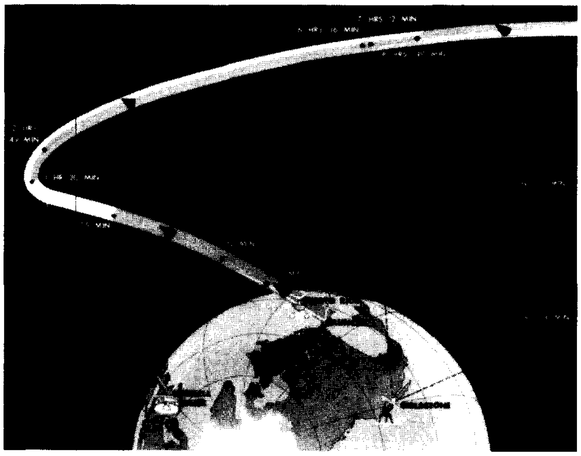

Figure 1. The apparent motion of space probes during injection phase, as viewed by a fixed ground observer or antenna station. Estimated times (after launch) for acquisition and loss of signal for JPL stations are marked on the drawing.

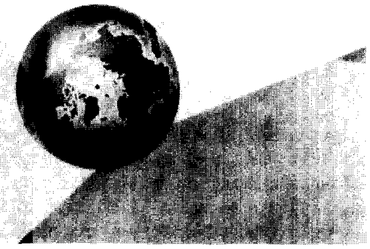

Figure 2. The coverage of space probes from three stations located 120° apart in longitude.

diately after launch from Cape Canaveral (Figure 1), a space probe travels rapidly to the east, as seen by an observer at a downrange station. Because of its constantly-increasing altitude, however, the probe's angular velocity gradually decreases. When the probe's angular velocity decreases to that of the Earth's rotational velocity, it momentarily becomes stationary over a specific point on the Earth's surface (generally over southern Africa or the Indian Ocean).

As the angular velocity of the probe continues to decrease, it then apparently moves westward, from the perspective of an observer at a ground station. Eventually, its apparent motion from the eastern to the western horizon closely approximates (but not quite equates) that of a fixed astronomical radio source. To the observer at a ground station, the greatest components of the probe's apparent motion, from then on, are due to the rotation of the Earth. Such rotation obviously results in the probe apparently moving across the sky from the eastern to the western horizon of a particular antenna station, once each day. Simple geometry dictates that the minimum number of principal antenna stations that permits continuous, overlapping monitoring of space probes, after completion of the injection phase, is three (Figure 2). Because the world is divided into 360° of longitude, the three stations should thus ideally be located approximately 120° apart in longitude. These three principal stations would, of course, be supplemented by launch-point and down-range stations, for monitoring the probes during their injection phase.

ARPA imposed time and funding constraints on JPL and STL in 1958, however, and thus the networks of stations that they produced were less than ideal, as will be shown below.

3. The STL network

There was a relatively short time (approximately five months) between the ARPA authorization announcement and the date (initially set for August 22) for the Air Force's first attempted lunar-probe launch. Because of this, the network of stations that STL set up to support the probes (initially under the direction of Frank Lehan, associate director of Ramo-Wooldridge's Electronics Research and Development Division) was, by necessity, hastily constructed. It consisted, for the most part, of equipment originally designed for other purposes and modified for the special requirements of the lunar missions. Two antennas were already erected and in use for radio-astronomy and radar experiments.

The location of the two largest antennas in STL's network was governed by the roles they would play in communicating with the lunar probes, while they were in the vicinity of the Moon. Because STL intended to insert the Air Force probes into orbit around the Moon, a station with a command transmitter needed to be located at a longitude that would allow it to have a favorable look angle at the probes, at the time of the fourth-stage retro-rocket firing, and for approximately six hours thereafter. Preliminary trajectory analysis indicated that the United States Territory of Hawaii, in the Pacific Ocean, would satisfy this requirement. Specifically, STL chose a site at South Point, on the island of Hawaii, the southern-most point in the Hawaiian-island chain. In addition to having an unobstructed view of the southern horizon, the site had the advantage of nearby volcanic mountains. These would shield the station from potential radio interference emanating from the nearest sizable towns, Kailua and Hilo, each about 70 miles away. Also, the site was not under any air-traffic route [6].

STL installed a 60-foot-diameter parabolic antenna at the site. This was a modification of the TLM-18 antenna (Figure 3), that Radiation, Inc., was currently manufacturing for use in the forthcoming Air Force Discoverer reconnaissance-satellite program.

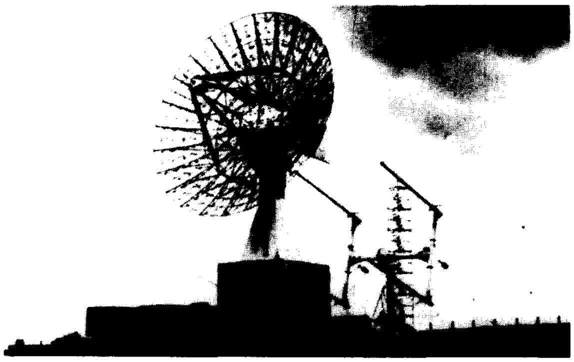

Figure 3. The 60-foot-diameter parabolic antenna installed by STL at South Point, Hawaii. In the foreground is one of four surrounding helical-array antennas that formed an interferometer array to be used to locate the Air Force lunar probes, and to direct pointing of the large antenna.

Mounted on a 70-foot-high tower of steel and concrete, it was capable of rotation through 360° in azimuth and 95° in elevation.

In its "Project Baker" proposal, STL had pointed out that the principal picture-receiving antenna would have to have "a clear view" (i.e., a direct line of sight) of the Moon, shortly before the initially-planned impact of the spacecraft on the surface. For a launch from Cape Canaveral, the company calculated that the impact would occur when the Moon was approximately over the 0°-longitude meridian on Earth: a meridian that passed through England, France, Spain, and several countries in western Africa. Although the mission of the lunar probes was subsequently changed to orbiting the Moon, this longitude remained the ideal location, because mission planners would want to attempt the picture taking as soon as feasible, i.e., as the spacecraft made its initial close approach to the Moon, before anything might go wrong with the spacecraft. As for the size of the picture-receiving antenna, STL noted in its proposal that one 60 feet in diameter could obtain a television picture of only moderate quality, unless transmission was slowed down to a rate of one picture per ten seconds. On the other hand, the company pointed out, "greatly improved picture quality" could be obtained if an antenna 200 ft in diameter were used to receive the picture signals [7].

Erecting a new antenna with a diameter of 200 ft or more, especially in a foreign country, in only five months was, of course, not possible. STL was aware, however, of an already-erected antenna, in this size range, near the desired meridian: the University of Manchester's Jodrell Bank 250-foot-diameter radio telescope (Figure 4), near Manchester, England. It had received much publicity the previous fall, when it detected the signals being transmitted by the Soviet Union's Sputnik satellites. A secret meeting between Air Force Lt. Col. Donald R. Latham (coordinator of the Ballistic Missile Division teams working with STL) and Bernard Lovell, director of the Jodrell Bank facility (an encounter that Lovell later described in some detail in his 1968 book, *The Story of Jodrell Bank*) led to temporary use of the antenna during the lunar-probe missions by STL, which shipped over and installed an appropriate antenna feed, and other specialized equipment [8].

Figure 4. The University of Manchester's 250-foot-diameter Jodrell Bank radio telescope.

Figure 5. The MIT's 84-foot-diameter Millstone Hill parabolic antenna.

STL erected and/or made use of three other antenna stations to support the probe missions. At Cape Canaveral, the company installed two helical antennas about two miles from the Thor-Able launch pad: one for transmitting, and one for receiving. These antennas would participate in the pre-launch checkout, monitor the velocity of the launch vehicles in the period immediately following launch, issue separate commands to shut down the second stages and to fire vernier rockets at the proper times, and receive telemetry until the probes disappeared over the eastern horizon [9]. For monitoring the probes further along their injection trajectory, the Air Force made available an 84-foot-diameter parabolic antenna (Figure 5) in Millstone Hill, Massachusetts, that MIT's Lincoln Laboratory operated as a radar installation for the service. This antenna, manufactured by D. S. Kennedy and Company, would be used to obtain both tracking data and to receive telemetry [10]. Finally, because the Hawaii and Jodrell-Bank antennas were more than 200° apart in longitude, STL installed in Singapore an intermediate probe-monitoring station, comprised of a helical-antenna array and associated equipment [11].

Due to time limitations, STL chose an operating radio frequency of 108 MHz for its probes, the same frequency that was being used in the Vanguard and Explorer satellite programs. At all of their antennas, they also used the phase-lock receivers that JPL had developed for the Microlock stations, set up to support the Explorer satellites.

Initially, STL appears to have given little thought as to what might constitute a permanent system of stations, for supporting an ongoing program of un-manned solar-system spacecraft exploration, and whether any of the stations that they would install or modify in the short term could become part of such a permanent system. By contrast, JPL, which would work closely with the Army Ballistic Missile Agency on the Army lunar probes, began planning for a permanent system even before the ARPA authorization was issued.

4. The JPL network

The first Army lunar-probe attempt was originally scheduled for launch no earlier than November, 1958, about three months after the first Air Force attempt. JPL engineers used that extra time to design and implement a communications system that could satisfy not only the immediate requirements of the Army lunar probes, but also be adaptable for supporting more-demanding missions in the future, such as to Mars and Venus, the planets nearest the Earth. Such follow-on missions, obviously not included in the mandate of the March 27 ARPA authorization, were, in fact, being seriously studied by JPL as early as the spring of 1958. Four of the engineers most heavily involved in designing the communications system for the Pioneer lunar probes (Eberhardt Rechtin, head of the Guidance Research Division; Walter K. Victor, head of the Electronics Research Section; Robertson Stevens, head of the Guidance Techniques Research Section; and William Merrick, head of the Antenna Structures and Optics Group) later recalled the mixture of short-term and long-term design considerations that they kept in mind in selecting the first elements of that system:

> The total time available between initial design and operational status was less than 10 months. An appreciable capital investment was anticipated; consequently, an expendable-equipment philosophy could not be used. Because firing times were closely controlled by orbital considerations, it was important that the communications system be all-weather in order that vehicle firings would not be precluded by poor weather at the tracking and telemetering stations located around the world. Because it was virtually certain that deep space exploration would continue in the coming years, it was important that the basic design be commensurate with the projected state of the art, specifically with respect to parametric and maser amplifiers, increased power and efficiency in space vehicle transmitters, and future attitude-stabilized spacecraft. In addition, the limited number of firings in the program demanded that the communication system work reliably the first time and be relatively unaffected by large dispersions from the anticipated vehicle trajectory. [12]

JPL's anticipation of the requirements of future missions would be reflected in three critical choices that its engineers had to make in the spring of 1958: the type of antenna to be used at the principal ground stations, the locations of the principal stations, and the radio frequency at which the flight transmitter would operate.

4.1 Antenna selection

JPL engineers quickly realized that the procurement, fabrication, and erection of the principal ground-based antennas was the "longest-lead-time item" of the Pioneer lunar-probe program, particularly if they were to be chosen with a continuing long-term program of solar-system exploration in mind. In other words, more than any other aspect, this activity would require the longest period of time to complete. With this requirement in mind, Rechtin and Stevens, apparently anticipating a lunar-probe program, assigned Merrick to begin a survey of available antenna designs on February 7, nearly seven weeks before ARPA officially authorized the lunar-probe attempts.

Stevens initially specified an accuracy of six minutes of arc, but soon changed this requirement to two minutes "with better accuracy desirable." Merrick quickly discovered that such a level of accuracy had been obtained only by radio-astronomy antennas, under the optimal conditions of night-time operation and winds of less than 20 mph. Communications with probes beyond the Earth's atmosphere, however, would often have to occur under less than these optimal conditions, and thus the requirements for the space-probe ground-support antenna would be more demanding. According to Merrick and colleague H. B. Bell, these were as follows:

> *Wind*–Since missile [launch vehicle] firings cannot be held up because the wind is blowing somewhere around the earth nor can the bird [spacecraft] be whistled back from a space mission when the wind comes up, the antenna was required to be usable in winds of 60 MPH and to be capable of withstanding winds of 120 MPH.
>
> *Sunlight*–It is mandatory that missile tracking antennas be operable on a 24 hour basis. Therefore the tracking accuracy must be maintained regardless of solar exposure and rapid ambient temperature changes.
>
> *Slew-Rate*–Radio Astronomy type instruments are usually designed so that movement is at a maximum rate of 10 degrees per minute to a selected pointing direction. Observations are then made as the earth's rotation causes the source to appear to transit the antenna beam. [Pioneer] mission requirements dictated that the antennas be capable of continuously tracking the source and delivering "real time" directional and telemetering data to the specified accuracy. In order to track both deep space probes and satellite missions, tracking speed ranges were required from 1/10th degree per minute to 60 degrees per minute.

In summary, Merrick and Bell concluded that the ground-support antenna had to combine the best features of a precision radio-astronomy antenna and a precision guidance or tracking radar. Moreover, such an antenna had to be procured, fabricated, erected, integrated with electronic equipment, and tested, all prior to the planned first launch, in November. Merrick recalled that the astronomers and suppliers he consulted "questioned our sanity, competence in the field and/or our ability to accomplish the scheduled date even on an 'around the clock' basis." [13]

Given the limited time available and the fact that design, fabrication, and erection of existing radio-astronomy antennas had required anywhere from 18 months to 7 years, Merrick quickly concluded that the JPL requirements could only be met by "minor modification of an existing design." [14] He and his colleagues soon procured a survey of precision radio-astronomy instruments, recently compiled by Caltech radio astronomer John Bolton [15]. They intensively studied a just-published issue of the *Proceedings of the IRE* that was devoted to a comprehensive study of the radio-astronomy field [16]. During a ten-day trip, in late February and early March, Merrick and Stevens consulted various antenna vendors and users.

Various technical considerations led them to restrict the design to steerable two-axis-tracking parabolic reflectors, and to increase the desired diameter from 30 to 35 feet, then to 60 feet, and finally to 85 feet. Gradually, all but one design was eliminated from consideration. For example, the Jodrell Bank type of antenna was rejected because it was "too big and expensive," and its design and assembly had required seven years. The designs of the CSIRO's 210-foot-diameter antenna, at Sydney, Australia, and the NRAO's 140-foot-diameter antenna at Green Bank, West Virginia, were also eliminated from consideration, because these prototypes would not be completed until 1960. Foreign manufacture, high cost, inadequate aperture, and acknowledged design flaws were reasons for rejecting many other designs.

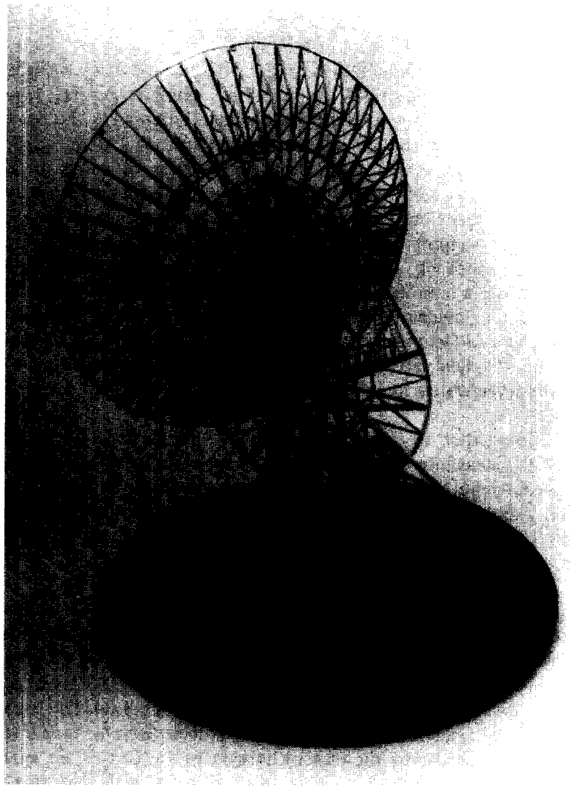

Figure 6. A model of the Blaw Knox 85-foot-diameter parabolic antenna.

Merrick and his colleagues ultimately chose a design (Figure 6) that had been initiated in 1953 at the Naval Research Laboratory, and had been developed further by Howard W. Tatel, at the Carnegie Institution of Washington. The design was refined by the Associated Universities, Inc., and had just been completed by the Blaw Knox manufacturing company. The 85-foot-diameter antenna had a cantilevered-equatorial mounting. It had very large hour-angle and declination drive gears, which gave high driving accuracy for relatively low tooth accuracy, and a low tooth loading during high winds. Blaw Knox, which priced the antenna at about $250,000, had already received orders from the University of Michigan and Associated Universities, Inc. (for erection at Ann Arbor and Green Bank, respectively), but neither had been completed when JPL placed its order, in April. Eventually, citing national priority, the Army was able to move the probe-supporting antenna to the front of the manufacturing line.

4.2 Antenna-station-site selection

JPL, with ARPA's approval, actually placed an order with Blaw Knox for three antennas (the number required for the "ideal" network), but only one was actually erected in 1958. Rechtin would later recall that the planned overseas stations "so rapidly became bogged down in approval red tape that their activation date moved from after the first probe [attempt] to after the second probe [attempt]." [17] Gaining approval for permanent erection of large antennas on foreign sites would obviously necessitate diplomatic negotiations with the desired host countries. More fundamentally, additional funds would be required for the construction of the stations, procurement of the necessary electronic equipment for these facilities, and the establishment of appropriate ground-communication links between these stations and JPL. As Congress shortly was expected to approve President Eisenhower's request for a civilian space agency, top officials of the Department of Defense, ARPA's parent institution, were understandably unwilling to commit funds for antennas that were needed primarily for supporting a long-term space program, for which the department had no mandate.

Fortunately, the planned mission of the Army lunar probes enabled Rechtin and his fellow engineers to make do with only one principal antenna within the United States. Unlike the Air Force probes, they would only fly by the Moon, and the desired pictures would be taken automatically when a photocell mechanism indicated that the probes were within a certain distance of the Moon. Thus, no transmitter would be needed to issue retro-rocket firing commands to insert the probe in lunar orbit, or to operate the camera. Additionally, JPL deliberately selected a trajectory that would cause the probes to arrive at the vicinity of the Moon when they were in the line of sight of the single, principal antenna.

JPL developed certain basic criteria for choosing a site for this antenna. It preferably should be within a natural bowl, so that surrounding terrain could shield it from radio noise generated from nearby towns and ground vehicles. The noise level in general should be low, and thus areas with power lines, radio stations, radar transmitters, sheriff's radios, and/or considerable numbers of aircraft passing overhead should be avoided. Government-owned land was mandated, because the schedule and funding of the Pioneer program did not permit the acquisition of private land. Because of the size of the steel components of the antenna, an access road was

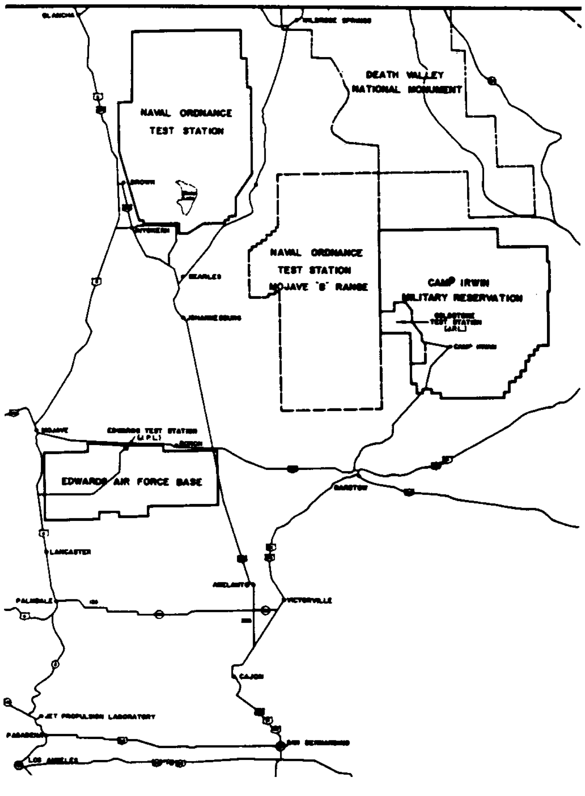

Figure 7. A map of the Goldstone station site and the surrounding area.

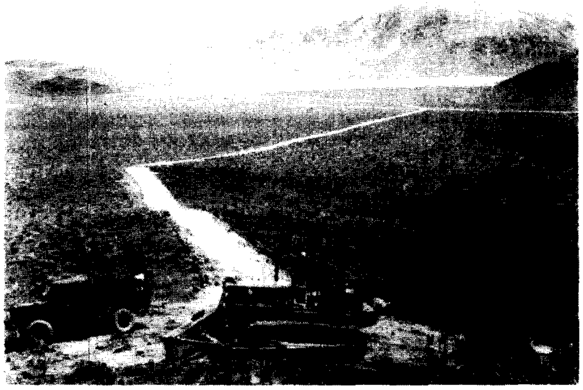

Figure 8. A bulldozer and the access road near Goldstone Dry Lake.

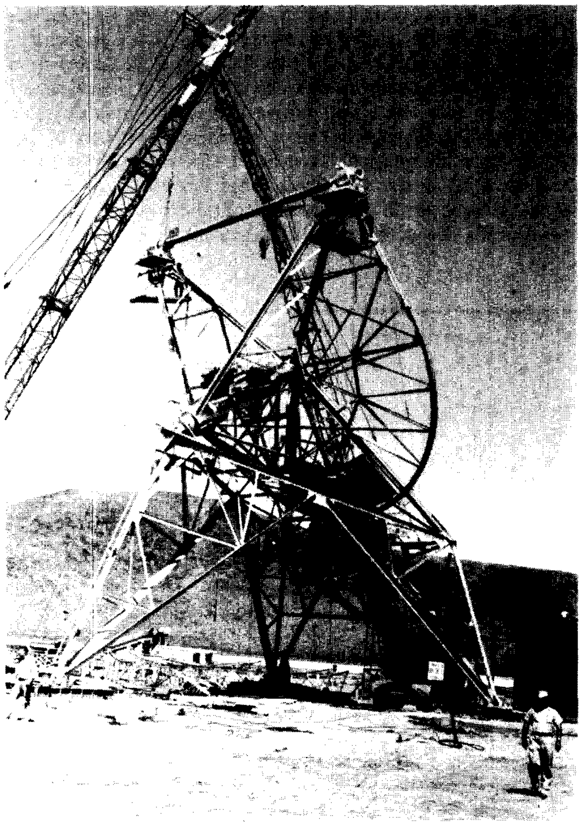

Figure 9. The Goldstone antenna under construction.

required. The soil had to be suitable for accurate and stable support of the antenna. [18]

Fortunately, JPL identified such a site near the Goldstone Dry Lake within the Army's Fort Irwin, located in the Mojave Desert, about 150 miles northeast of Pasadena (Figure 7). The site had been initially surveyed by JPL personnel in 1956, when they began seeking an off-lab site to test rocket engines [19]. JPL never succeeded in obtaining funds for establishing such a facility there, but in late March, 1958, the lab recognized the suitability of the Goldstone site for the antenna [20].

After General John B. Medaris, the head of the Army Ballistic Missile Agency, overruled, in mid-May, another general who wanted to use the area for a proposed missile-firing range, the work needed to convert the site into the desired antenna station facility swung into high gear. It began with construction of access roads (Figure 8), and test corings of the antenna foundation. By early July, the antenna base was laid, and by early August, construction of various support buildings was completed. The steel for the antenna arrived on August 11. Five days later, under Merrick's supervision, a crew from the Radio Construction Company began erecting the antenna (Figure 9). Shortly after they completed their work, in mid-October (Figure 10), the feed was installed, and a series of optical and radio-frequency tests were conducted, to establish the system tracking accuracy [21].

In addition to the Goldstone facility, JPL engineers installed two supplementary antenna stations, to support the Pioneer lunar-probe attempts. For much the same reasons as their counterparts at STL, they desired a facility at Cape Canaveral, and ultimately settled on a 6-foot-diameter circularly-polarized parabolic antenna (Figure 11), for their launch-point station [22].

During the spring of 1958, two developments necessitated the installation of an additional station, down range. One was the dimming prospect for JPL to have a network of three principal stations. In particular, the lack of a station approximately 120° east of Goldstone would create a coverage gap of approximately two hours in the reception of signals from the probes: from the time that they descended below the eastern horizon of the Cape Canaveral station (approximately 15 minutes after lift-off), until they reappeared above the same horizon during their subsequent apparent motion from east to west. During that period, the probe's azimuth would change by 25°. This change, alone, would make reacquistion difficult, but additionally, as one early JPL report observed, "acquisition may not be possible if certain launch conditions are off from their nominal values." The long gap in reception of radio signals would make the early determination of the actual trajectories of the probes more difficult and, in turn, the proper pointing of the Cape Canaveral and Goldstone antennas.

The discovery by the early Explorer satellites, of the Van Allen radiation belt, provided a second reason for establishing a down-range station. Perhaps at the behest of government science officials, James Van Allen, the principal investigator for the Explorer cosmic-ray experiments, proposed and won approval for

Figure 10. The completed antenna near Goldstone Dry Lake.

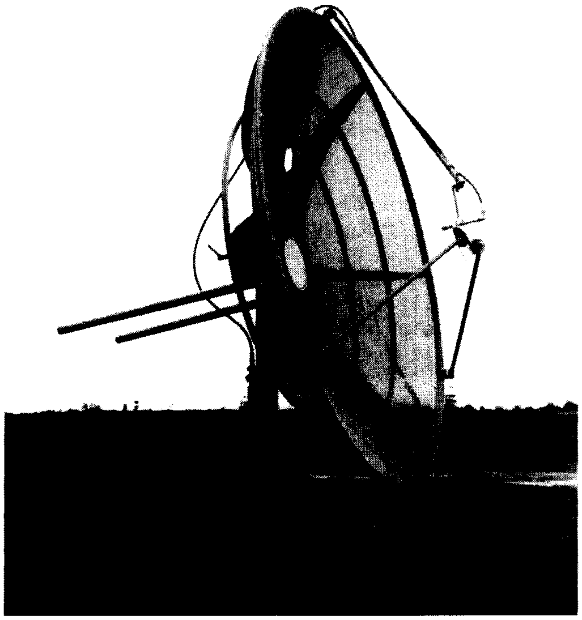

Figure 11. The six-foot-diameter circularly-polarized parabolic antenna installed by JPL near the launch pad at Cape Canaveral.

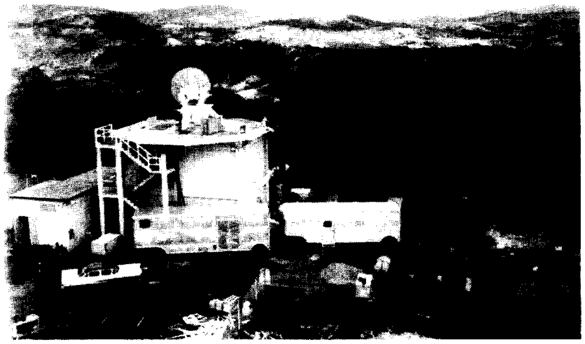

Figure 12. The 10-foot-diameter circularly-polarized parabolic antenna, installed by JPL near Mayaguez, Puerto Rico. The antenna, shown here before radome installation, was placed atop an old Atlantic Missile Range station structure.

the addition of similar instruments on the Pioneer lunar probes, in order to determine the full radial structure and outer boundaries of the belt. A down-range station would permit reception of the scientific telemetry during the crucial period when the probe ascended through the altitude region of interest above the Earth–a period that would occur before the probe appeared above Goldstone's eastern horizon [24].

After briefly considering the British island of Antigua, in the Caribbean Sea, JPL engineers ultimately selected a site (Figure 12) at the Atlantic Missile Range station, three miles from the city of Mayaguez, on the west coast of the island of Puerto Rico [25]. Because the probes would be moving relatively fast as they passed over this station, they decided to use a 10-foot-diameter circularly-polarized parabolic antenna that could slew at a faster rate than the larger antenna at Goldstone. They enclosed both the antenna and its pedestal in an inflatable radome, because the pedestal servo system could not accurately position such a large antenna under even moderate wind conditions [25].

4.3 Frequency selection

Unlike their counterparts at STL, JPL communication engineers chose not to operate at the 108 MHz frequency being used for the Vanguard and Explorer satellites. With future missions clearly in mind, they noted in an early report that the presence of interference at frequencies below 500 MHz would "seriously limit the growth potential of any space communication technique" using a frequency in this region [27].

Victor, assigned by Rechtin to choose an operating frequency for the Pioneer probes, in early April initially favored one in the region from 1365 to 1535 MHz because: (1) it had the least amount of interference currently and in the immediate future; (2) it stood the best chance for permanent approval by the Federal Communications Commission; (3) it bracketed the radio-frequency band of 1400 to 1427 MHz (the 21-cm hydrogen line), where Victor expected significant hardware developments to improve receiver sensitivities; and (4) its nearness to this band would allow astronomers to participate in communications with the lunar probes "without too much additional work on their part." [28]

Several colleagues, however, soon gave him convincing reasons to instead set the frequency at 960 MHz. They pointed out that a flight transmitter at the higher frequency would be half as efficient as one at the lower frequency, and also that considerably more modifications of existing hardware would be needed to construct a transmitter at the higher frequency than at the lower one. [29]

5. Epilogue and conclusion

The hard work that STL and JPL communication engineers expended in setting up their respective systems of antenna stations, in relatively short time periods, paid off in very satisfactory operation during the actual missions. The lunar probes themselves, however, failed to achieve the principal goal underlying their approval: a first-ever close-up photograph of the Moon, which might restore to the United States the international prestige that had been lost as a result of the USSR's successful orbiting of *Sputnik 1*, the world's first artificial satellite. Various rocket failures prevented all three of the Air Force probes, and the first of the Army probes, from reaching escape velocity. Only the second Army probe, *Pioneer 4*, launched on March 3, 1959, did so, but it passed too far away (37,000 miles) from the Moon to activate the camera system. Alas (from the standpoint of the US), by then the USSR's *Luna 1*, launched on January 2, had already passed within 6,000 miles of the lunar surface. *Luna 3*, launched on October 4, 1959, took the first photographs of the far side of the Moon.

On the other hand, JPL's concern about designing a communication system to support not only the Pioneer lunar probes, but also potential future missions to the Moon and planets, would lead to the evolution of their system into NASA's Deep Space Network. The Goldstone Pioneer station would form the cornerstone of the ideal network of three stations, spaced approximately 120° apart, that would be built in the next two years. In fact, a second triplet of stations, to handle an increased number of missions, was installed by the mid-1960s. In the early and mid-1960s, NASA and JPL, together with cooperating agencies abroad, would install additional 85-foot-diameter antennas at Goldstone; at the Woomera rocket range and at Tidbinbilla (near Canberra), in Australia; at Hartebeesthoek (near Johannesburg), in South Africa; and at Robledo de Chevala and Cebreros (near Madrid), in Spain. The selection of all these sites would be guided by the same technical criteria that had led to the selection of Goldstone site. Finally, Ranger, the first lunar program initiated by NASA, and *Mariner 2*, the first spacecraft to successfully fly by the planet Venus, would use the 960 MHz frequency originally chosen for Pioneer. NASA and JPL would move up to the higher frequency of 2295 MHz only in the mid-1960s, with the first missions of the Surveyor and Lunar Orbiter programs, and later missions of the Mariner program.

Acknowledgments

This article was based on research conducted for a book-length history of the Deep Space Network, that I have been writing under contract to the Jet Propulsion Laboratory. The contract was funded at the instigation of, and technically monitored by, Dr. Nicholas A. Renzetti, of JPL. I am grateful to Dr. Timothy C. Hanley, and his staff at the Space Systems Division History Office, Los Angeles Air Force Base, for allowing me to consult old Ballistic Missile Division records that were the basis of the STL section of the article. I am also grateful to the staffs of the JPL Library (especially Vladimir Petrov) and JPL Vellum File, for allowing me to consult the Historical Collection records, collected by R. Cargill Hall, and the microfilmed JPL Central File records, both of which are now in the JPL Archives. I would like to thank Dr. Eberhardt Rechtin (the first director of the DSN, and now a professor of engineering at the University of Southern California) and Dr. Sylvia D. Fries (former director of the NASA Headquarters History Division Office, and formerly a technical monitor on my contract) for many helpful comments on an early draft of the DSN history chapter, on which this article is based. Finally, I am gratefull to Dr. Frederik L. Mebeker for inviting me to present an early version of this paper at an historical session of the IEEE/ERA WESCON'92 conference at Anaheim, California, in November, 1992.

References and notes

[The following abbreviations are used:
SSDHO: Space Systems Division History Office
LAAFB: Los Angeles Air Force Base
SRS: JPL's *Space Research Summary* (see Reference 21)
SPS: JPL's *Space Programs Summary* (see Reference 21)]

1. "Secretary McElroy Announces New Space Programs," Department of Defense News Release No. 288-58, March 27, 1958.

2. A. F. Donovan (head of STL's Astrovehicles Laboratory) to Louis G. Dunn (STL executive vice president and general manager), "Meeting with Killian Subcommittee on Space with Reference to Project Baker" (Ramo-Woolridge interoffice memorandum GM 58-0165-06470), March 5, 1958, pp. 1-2, "Able-1 (Lunar Probe)" folder, SSDHO files, LAAFB.

3. JPL, *Project Red Socks*, October 21, 1957, Historical Collection (document 2-581b), JPL Archives.

4. STL, *Project Baker: Hard Impact Lunar Flight Experiment* (Exhibit 1 to Proposal 26-10), January 27, 1958, SSDHO files, LAAFB.

5. Brig. Gen. O. J. Ritland (Vice Commander, Ballistic Missile Division) to Asst. Chief of Staff for Guided Missiles, USAF Headquarters, "Astronautics Instrumentation Sites," May 12, 1958, "Able-1 (Lunar Probe)" folder, SSDHO files, LAAFB.

6. STL, *1958 NASA/USAF Space Probes (Able-1) Final Report. Volume 3. Vehicles, Trajectories, and Flight Histories*, February 18, 1959, pp. 86-90, SSDHO files, LAAFB.

7. STL, *Project Baker*, p. 27.

8. Bernard Lovell, *The Story of Jodrell Bank*, New York and Evanston, Harper & Row, 1968, pp. 186-87.

9. Air Force Ballistic Missile Division, *Lunar Probes Program Status Report*, June 1958, p. 10, and July 1958, p. 6, SSDHO files, LAAFB.

10. The use of the Millstone Hill facility was arranged during a visit by Lt. Col. Latham and STL's Albert Moreno to Lincoln Laboratory on May 23, according to Col. Lawrence D. Ely, "Visit to Lincoln Laboratory, Regarding Project ABLE-1," May 26, 1958, "Able-1 (Lunar Probe)" folder, SSDHO files, LAAFB.

11. STL, *Able-1 Final Report* [see reference 6], pp. 94-95; AFBMD, *Lunar Probes Program Status Report*, June 1958, p. 10, and July 1958, p. 5, SSDHO files, LAAFB.

12. W. D. Merrick, E. Rechtin, R. Stevens, and W. K. Victor, "Deep Space Communications," *IEEE Trans. Military Elect.*, **MIL-4**, pp. 156-62, April-July 1960.

13. W. D. Merrick and H. B. Bell to V. C. Larsen, Jr., "Vendor Selection for Large Ground Antennas," April 1, 1959, pp. 1-2, copies in Historical Collection (document 7-55), and "Satellite Tracking 1959" section, microfilm roll 614-93, both in JPL Archives.

14. Merrick to Larsen, "Vendor Selection for Ground Antenna," April 8, 1958, p. 1, "World Network 1958" folder, Rechtin files, DSN History Project Archives, JPL.

15. Later published as J. G. Bolton, "Radio Telescopes," pp. 176-209, in Gerard P. Kuiper and Barbara M. Middlehurst (eds.), *Telescopes* (Stars and Stellar Systems series, vol. 1), Chicago, University of Chicago Press, 1960. I am grateful to Harry Minnett for bringing the published version of this survey to my attention.

16. *Proc. IRE*, **46**, no. 1, pp. 1-355, January, 1958.

17. Rechtin to J. E. Froehlich (Explorer project manager, JPL), "Trip on ARPA World Net Problem," p. 3, "Trip Reports 1958" section, microfilm roll 614-104, JPL Archives.

18. Lt. Col. Glenn Crane to Col. Zierdt, "Goldstone Site for JPL," May 16, 1958, Historical Collection (document 3-1260), JPL Archives.

19. V. C. Larsen, Jr., to T. E. Carpenter, February 14, 1958, Historical Collection (document 3-1260), JPL Archives.

20. R. L. Lennard to Those Concerned, "Juno II Payload Meeting March 26, 1958," March 27, 1958, "Juno Internal Correspondence 1/58-4/58" section, microfilm roll 211-2, JPL Archives.

21. For lengthy descriptions of the Goldstone station during this period, see JPL, *Space Research Summary No. 1 for the period 15 May 1958 to 15 July 1958*, August 1, 1958, pp. 41-43 and 50-60; JPL, *SRS No. 2 for the period 15 July 1958 to 15 September 1958*, October 1, 1958, pp. 53-61; JPL, *SRS No. 3 for the period 15 September 1958 to 15 November 1958*, December 1, 1958, pp. 28-33; JPL, *Space Programs Summary No. 1 for the period 15 November 1958 to 15 January 1959*, February 1, 1959, pp. 45-74;

K. W. Linnes, W. D. Merrick, and R. Stevens, "Ground Antenna for Space Communication System," *IRE Trans. Space Elect. Telemetry*, **SET-6**, no. 1, pp. 45-54, March, 1960; M. H. Brockman, H. R. Buchanan, R. L. Choate, and L. R. Malling, "Extra-Terrestrial Radio Tracking and Communication," *Proc. IRE*, **48**, no. 4, pp. 643-54, April, 1960; and Allen E. Wolfe (ed.), *Juno Final Report, Volume II - Juno II: Space Probes* (JPL Technical Report No. 32-31), September 12, 1960, pp. 42-45. See also "Company Profile: Jet Propulsion Laboratory, Pasadena, California," *Microwave J.*, **4**, no. 3, pp. 131-35, esp. p. 133, March, 1961.

22. For lengthy descriptions of JPL's Cape Canaveral launch-point station, see JPL, *SRS No. 1*, pp. 67-69; JPL, *SRS No. 2*, pp. 46-47; JPL, *SRS No. 3*, pp. 23-28; JPL, *SPS No. 1*, pp. 32-35; and Wolfe (ed.), *Juno Final Report, Volume II*, pp. 21-25.

23. James A. Van Allen, *Origins of Magnetospheric Physics*, Washington, Smithsonian Institution Press, 1983, p. 86.

24. Rechtin to John D. Nyquist (Executive Director, Systems Division, Collins Radio Company), May 28, 1958, copies in "Juno-Collins Radio 1958-1959" section, microfilm roll 33-1A, and "Collins Radio (K-39436) Jan. thru July 1958" section, microfilm roll 614-220, JPL Archives.

25. The choice of the Mayaguez site was based on a site survey conducted by JPL's Henry N. Levy and Robert T. Brice, together with Capt. Henry Paul from the Army Project Office at Patrick Air Force Base (adjoining the Air Force Missile Test Center at Cape Canaveral). For details of the survey, see Levy and Brice to P. A. Tardani, "Trip Report," July 8, 1958, "Trip Reports" section, microfilm roll 614-104, JPL Archives.

26. For lengthy descriptions of the JPL's Puerto Rico down-range station, see JPL, *SRS No. 1*, pp. 43-44 and 60-67; JPL, *SRS No. 2*, pp. 47-52; JPL, *SRS No. 3*, pp. 25-28; JPL, *SPS No. 1*, pp. 35-44; and Wolfe (ed.), *Juno Final Report, Volume II*, pp. 25-38.

27. JPL, *SRS No. 1*, p. 36.

28. W. K. Victor to All Concerned, "Radio Frequencies for the Juno Program," April 7, 1958, copies in "Juno Administrative" section, microfilm roll 33-1A, and "Satellite Tracking 1958" section, microfilm roll 614-93, JPL Archives.

29. W. K. Victor to All Concerned, "Radio Frequencies for Juno," April 10, 1958, copies in "Juno Administrative" section, microfilm roll 33-1A, and "Satellite Tracking 1958" section, microfilm roll 614-93, JPL Archives.

Introducing Historical Article Author Craig B. Waff

Craig B. Waff received the BS degree in mathematics, from the University of Florida, in 1969, and the PhD degree, in history of science, from the Johns Hopkins University, in 1976. While at Hopkins, he received a Woodrow Wilson Foundation Dissertation Fellowship.

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