Chapter 2

THE MARINER ERA MISSION SET

The worldwide network, envisioned by Rechtin in 1958, became a reality between July 1959 and July 1961. In that hectic two-year period, funding was proposed and approved, international agreements were negotiated, suitable sites were found, equipment was procured and shipped overseas, roads and facilities were built, and JPL contractors erected antennas and installed equipment. The Deep Space Instrumentation Facility now consisted of a real network of 26-meter-diameter antennas located at intervals of approximately 120 degrees of longitude around the globe. Two such antennas were located at Goldstone, California, and one each at Johannesburg, South Africa, and Woomera, Australia. A world view of the DSIF as it existed at that time is shown in the figure below.

Figure 2-1. World view of the Deep Space Instrumentation Facility, 1961. Although the locations of future sites, near Canberra, Australia, and near Madrid, Spain, are also shown on this diagram, they had not been established at that time.
Teletype and telephone circuits linked the stations to a rudimentary flight operations control center at JPL. In the 1961 photograph of the operations control center at JPL shown in Figure 2-2, the presence of rotary telephones, mechanical calculating machines, wall boards, and mechanical status displays is a poignant reminder of the pre-digital age.

At JPL and at each of the tracking stations, highly motivated crews of operators and engineers were trained to operate and maintain the complex, state-of-the-art equipment that JPL had designed and tested, but not yet demonstrated, to communicate with distant spacecraft.

At the same time, DSIF planners knew that in the years ahead, the network would be called upon to support much more complex missions to the Moon, missions to fly by and possibly even orbit Venus and Mars, and heliocentric probes to measure fields and particles and the solar wind in interplanetary space. At the extreme limit of possibility lay spacecraft encounters with Jupiter and Saturn.

Figure 2-2. Flight operations control center, JPL, 1961.
To appreciate the magnitude of the challenge facing the embryonic DSIF at that time, it is instructive to arrange this inventory of future missions into a mission set in the following way:

Deep Space Mission Set for the Mariner Era

<table>
<thead>
<tr>
<th>Program</th>
<th>Type</th>
<th>Launches</th>
<th>Missions</th>
<th>First Launch</th>
<th>Last Launch</th>
<th>Span</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ranger</td>
<td>Lunar Photo</td>
<td>9</td>
<td>3</td>
<td>Aug 61</td>
<td>Mar 65</td>
<td>4 yrs</td>
</tr>
<tr>
<td>Mariner</td>
<td>Venus, Mars flyby</td>
<td>0</td>
<td>7</td>
<td>Jul 62</td>
<td>Nov 73</td>
<td>11 yrs</td>
</tr>
<tr>
<td>Pioneer</td>
<td>Interplanetary</td>
<td>4</td>
<td>4</td>
<td>Dec 65</td>
<td>Nov 68</td>
<td>3 yrs</td>
</tr>
<tr>
<td></td>
<td>Jupiter</td>
<td>2</td>
<td>2</td>
<td>Mar 72</td>
<td>Apr 73</td>
<td>1 yr</td>
</tr>
<tr>
<td>Apollo</td>
<td>Pilated</td>
<td>2</td>
<td>7 Test</td>
<td>Nov 67</td>
<td>Dec 72</td>
<td>5 yrs</td>
</tr>
<tr>
<td></td>
<td>Lunar</td>
<td>14</td>
<td>6 Landers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surveyor</td>
<td>Lunar Lander</td>
<td>7</td>
<td>5</td>
<td>May 66</td>
<td>Jan 68</td>
<td>2 yrs</td>
</tr>
<tr>
<td>Lunar Orbiter</td>
<td>Lunar Orbiter</td>
<td>5</td>
<td>5</td>
<td>Aug 66</td>
<td>Aug 67</td>
<td>1 yr</td>
</tr>
</tbody>
</table>

As this table makes clear, all launches did not necessarily result in successful missions. Failures were a common feature of the early programs but the failure rate greatly improved as time went on. The Ranger program is an example. The launch span, the time between the first and last launches of individual programs, is an indicator of the program’s impact on the DSIF. Many launches in a short span affected the level of tracking activity for the DSIF but did not require significant new technology between launches. Lunar Orbiter and Surveyor were such programs. The reverse was true for programs with a long launch span like Pioneer and Mariner.

In terms of influence on the growth and technical development of the network, the Mariner program exceeded all of the other programs in both complexity and launch span. It did not produce the longest duration missions, however. The Pioneer program would still have viable missions in flight long after the last Mariner mission ended in 1974. Nevertheless, the Mariner program drove the early development of new capabil-

ity for the DSIF to a greater extent than any other program and, at a time before the public and scientific palate had become jaded with a surfeit of “solar system science,” it produced many of NASA’s most spectacular scientific results. For that reason, the period of DSIF history that began with the disastrous launch of the first Ranger in 1961 and ended with the hugely successful Mariner 10 spacecraft in orbit around Mercury and Venus in 1974, is identified here as the “Mariner Era.”

Of the five projects included in the Mariner Era mission set, three, the Ranger, Mariner, and Surveyor projects, were fully managed by JPL. The Ames Research Center in Mountain View, California, directed the Pioneer Program, while Lunar Orbiter was directed by the Langley Research Center in Hampton, Virginia.

DSN participation in the Apollo program was directed by the Goddard Space Flight Center, Greenbelt, Maryland. Because these later projects were not controlled by JPL, the different management styles and demands for new standards of performance that they brought to the DSIF led to far-reaching changes in the DSIF arrangements for supporting non-JPL or “outside” flight projects. It was the sum total of these often conflicting influences that shaped the character and capability of DSIF during the Mariner Era.

In a real sense, the DSIF began its effective operational life as a complete operational network with the Ranger program, an ambitious JPL mission to land a spacecraft on the surface of the Moon, in August 1961.

The Ranger Lunar Missions

While one stream of activity in JPL had, over the past several years, been focused on the problems associated with approving, designing, and implementing the DSIF, the principal effort had been devoted to developing the first spacecraft specifically designed to reach the surface of the Moon. Designated the Ranger Program, this project had been assigned to JPL by NASA in December 1959 and was to be completed within 36 months.

The Ranger spacecraft were much more complex than the earlier Pioneer-type probes. In particular, the Rangers were to be attitude stabilized to keep their high-gain radio antennas pointed toward Earth and the three antennas of the DSIF. This also allowed the solar panels, which provided power for the spacecraft electronics, to remain pointed at the Sun during flight.
The battery powered Pioneers had been simply spun like an artillery shell to maintain their spatial orientation during flight. In addition to attitude stabilization and more advanced radio communication systems, some of the spacecraft would carry an ejectable capsule. This capsule would descend to the lunar surface on a small retrorocket and thereafter right itself to transmit data on local radio activity and moonquakes. Later models were to carry high definition video systems to return detailed pictures of the lunar surface prior to impact.

The original Ranger program comprised five spacecraft, the first two of which were to be test flights ejected into an elliptical orbit around Earth. These would be essentially engineering flights to check out the new capabilities of attitude stabilization and solar power for the spacecraft and, for the DSIF, the all important telecommunication design. The remaining three spacecraft would consist of a basic spacecraft “bus” with an ejectable capsule containing a science instrument package and the retrorocket to set it on the lunar surface. During the flight to the Moon, these spacecraft were to make fields and particle science measurements and, during the final moments of approach before impact, take close-up vidicon pictures of the lunar surface.

In retrospect, this appeared to be an ambitious plan indeed for a fledgling technology, as later events proved. However, at the time, it was perceived as the appropriate major step forward that was needed to reestablish the prestige and forefront position of American scientific endeavor, so adversely affected by the Russian success with Sputnik and Lunik some years previously.

Although all five of the first Ranger flights were unsuccessful due to launch vehicle and spacecraft system failures, the excellent performance of the DSIF proved that the worldwide network concept of tracking stations managed and controlled from a central location was not only feasible but would be an essential element of future space missions to other planets and the Moon.

The Ranger flights demonstrated the value of continuous communication between the spacecraft and the network stations. This provided the Mission Operation teams back in the Flight Operations Control Center with immediate information about the status and condition of spacecraft and operating systems during the entire flight. This included engineering and scientific data. Ironically, this capability allowed the spacecraft controllers to estimate the reason for all of the Ranger failures attributed to the spacecraft.
Following a soul-searching evaluation of the causes of failure of the first five Ranger missions, and some consequent reorganization of technical responsibilities at JPL, the program resumed in January 1964. The Ranger team redefined its objectives to the sole task of securing close-up television pictures of the lunar surface, ostensibly to aid in the design of two more sophisticated lunar missions then under study by NASA, namely the unpiloted Surveyor landers and the piloted Apollo program. Although the instrumented science capsule had been removed, the mission remained very ambitious for those days, as it included a launch into Earth-parking orbit followed by a second burn of the launch vehicle to transfer the spacecraft into a lunar trajectory. Attitude control maneuvers then followed to orient the solar panels to the Sun and the spacecraft antenna toward Earth. Further midcourse and terminal maneuvers were required to be correctly executed before the Ranger vidicon driven cameras could view the lunar surface for the brief period before final impact. During that time, the precious video data would be transmitted to the DSN stations where it would be processed and delivered to the Ranger team in the Operations Control Center at JPL.

With the reputation of JPL on the line, the first of the final group of four Rangers was launched in January 1964. Despite the political pressure to demonstrate success after the poor results from the first group of five launches, Ranger 6 was also a failure. It performed perfectly until the last 10 minutes before lunar impact, at which point the spacecraft television system should have turned on to start transmitting pictures to the Goldstone station. There was no indication that this happened, and no pictures were sent. The cause of this failure was attributed to high voltage “corona discharge” in the camera’s electrical insulation and appropriate changes were made to the TV subsystem on the remaining three spacecraft.

Six months later, the fortunes of the Ranger program changed dramatically. Ranger 7, launched in July 1964, was a resounding success and radioed 4,300 high-resolution pictures of the lunar surface back to Earth. Immediately after lunar impact terminated the flight, President Johnson called JPL and told Director William Pickering that Ranger 7 was “a magnificent achievement.” On behalf of the whole country he congratulated NASA, JPL, and NASA contractors, saying, “This is a basic step forward in our orderly program to assemble the scientific knowledge necessary for man’s trip to the Moon.” News conferences and presentations at the White House followed as soon as the films arrived at JPL from Goldstone and could be processed. The mood at NASA was elation, the Ranger team at JPL was ecstatic.
The final flights of the Ranger program in February and March 1965 added to the success of Ranger 7. Thousands more pictures of the lunar surface were returned by missions 8 and 9, and the reputation of JPL as a leader in the field of space exploration was established to worldwide acclaim.

No less delighted than those who were directly involved in the mission was the lunar science community, which, for the first time, had over 17,000 close-up pictures of the lunar surface for study and analysis. In addition, engineers and scientists designing the Surveyor and Apollo missions, soon to follow Ranger to the Moon, had a greatly improved basis for their designs.

In his History of Ranger project, Cargill Hall wrote, “No longer a liability, the Ranger program had vindicated American space policies and presaged accomplishments yet to come.” It had indeed, and they would not be long in coming.

Mariner Planetary Missions

Important as it was, Ranger was not the only program demanding the attention of the DSIF in 1962. By midyear, the first Mariner spacecraft, designed by JPL for planetary missions as distinct from lunar missions, were on their way to the launch pads at Cape Canaveral, Florida (later renamed Cape Kennedy).

Unlike lunar missions, planetary missions have only a very limited opportunity for launch, or “launch window,” which occurs every few years. For missions to Venus, 1962 was one such year, and the next opportunity for launch would not occur until 1964. NASA and JPL could not wait that long for a first planetary mission. The attempt to send a spacecraft to Venus would have to be made in 1962.

Since the time between the NASA go-ahead and the opening of the Venus launch window was less than a year, much of the Ranger technology, including the radio subsystem, was utilized for the Mariner spacecraft. For the DSIF, this meant a continuation of the L-band uplink and downlink support and the possibility of competition with Ranger for the attention of DSIF tracking stations when both Ranger and Mariner spacecraft would be in view at the same time.

This situation, which first appeared in the Ranger/Mariner Era, was to become of immense importance in the years ahead as the number of flight missions increased. Conflicts for use of the DSN antennas when view periods of different spacecraft overlapped were a
frequent occurrence. In the onrush of preparing the Mariners for launch the problem was deferred.

In addition to the existing 26-meter stations at Goldstone, Woomera, and Johannesburg, the DSN had, at the time of the first Mariner launches, grown to include a Launch Station at Cape Canaveral identified as DSIF 0, and a Mobile Tracking Station (DSIF 1), which was located near the Johannesburg station in South Africa.

It was the purpose of DSIF 0 to track the spacecraft as it lifted off the launch pad atop the launch vehicle, by manually pointing a small two-meter diameter dish antenna at the rapidly disappearing launch vehicle/spacecraft combination. This was not a job for the fainthearted, since the distance between the tracking antenna and the launch pad was necessarily short to ensure that the spacecraft signal was received continuously for as long as possible after liftoff. This period, seldom more than a minute or two, provided vital engineering information for the DSN regarding the status of the downlink as the spacecraft started its long journey around the world to reappear over South Africa at the next tracking station, DSIF 5.

There, the small 3-meter antenna of the Mobile Tracking Station rapidly acquired the spacecraft and used its pointing information to direct the large 26-meter antenna to the spacecraft. Once acquired, the spacecraft downlink was tracked and the data it carried was processed, recorded, and returned to JPL by airmail, a process which at that time could, and usually did, take seven days.

Mariner 1962

The first two Mariner spacecraft were essentially long-range versions of the Ranger spacecraft. They carried instruments to make scientific measurements in interplanetary space while moving along its trajectory between Earth and Venus. On arrival, they would measure the radiation and magnetic fields while the microwave and infrared radiometers analyzed Venus’ atmosphere. The spacecraft used the same type of radio system (L-band) as had been carried by the Ranger spacecraft.

Two complicated, inflight operations were to be carried out after launch. The first of these was the midcourse maneuver to correct the trajectory to aim it more precisely at Venus. The second maneuver would point the science instruments to scan the Venus surface as the spacecraft flew by. The commands to carry out the maneuvers would be sent from the tracking stations. The science data would be transmitted by the spacecraft’s three-watt transmitter to the DSN antennas, by then 58 million kilometers from...
the spacecraft. Data would “trickle” across those millions of miles of interplanetary
space at just over eight data bits per second. Apart from the tremendous scientific
value of the science data itself, this was regarded as a major technological achievement
at that time.

Mariner 1 was launched in July 1962, but was destroyed by the Range Safety when it
ran off course shortly after liftoff. However, Mariner 2 injected into a Venus trajectory
by an Atlas-Agena launch vehicle the following month, performed exactly as intended.
Following a perfect liftoff, DSIF 0 followed the spacecraft until it disappeared over the
horizon. The spacecraft appeared over South Africa some 28 minutes later and was
acquired by DSIF 1 with no problem. Within three minutes, the big, 26-meter
Johannesburg antenna had found the spacecraft and began receiving engineering data to
verify the spacecraft had survived the stresses of the launch environment.

The midcourse maneuver was carried out successfully and, after some further commanding
to correct a temperature problem, reached Venus in mid-December. After passing Venus
at a range of 40,000 miles, the spacecraft continued in orbit around the Sun until it
fell silent on 2 January 1963. The DSN stations searched the empty airwaves for sev-
eral days trying to find some sign of life from the first planetary spacecraft but none
was found. In its brief lifetime, Mariner had transmitted 11 million data bits of science
and engineering data back to Earth.

As a consequence of experience with the first Ranger and Mariner missions, the DSIF
began work to improve its capability so that engineering and science data could be
relayed back to JPL as it was received from the spacecraft, that is to say in real time.
Automatic monitoring of the DSIF stations would be added to permit the engineering
experts at JPL who had designed the station equipment originally to aid the remote sta-
tion staff in troubleshooting and problem identification. Even greater emphasis was to
be placed on good engineering practices, conservative design, and thorough testing to
minimize equipment failures in the field. Techniques to acquire the spacecraft downlink
as early in flight as possible were studied. Small wide-beam antennas for “initial acqui-
sition” were added to the network antennas and the accuracy of flight path predictions
was improved.

The experience gained from these early flights also led to a new approach to DSN
telecommunications link design, in terms of receiver sensitivity and transmission power
of the ground tracking station. Combined with similar considerations for the spacecraft
radio system, the basic concepts of uplink and downlink performance became firmly
established as the methodology for all future deep space communications engineering design.

**Mariner 1964**

A “launch window” for Mars only opens every 25 months, and such an opportunity occurred in late November 1964. To take advantage of this situation, NASA chose a Mars-1964 project based on JPL’s experience with the earlier Venus missions. Three spacecraft were to be built, two for flight, with one as backup that operated at the then-new S-band frequency.

The *Mariner 3* and *Mariner 4* missions were to be supported with the existing DSIF 26-m stations at Goldstone, Johannesburg, and Woomera, plus a new station in Australia which had been built at Tidbinbilla near Canberra. The stations at Woomera and Johannesburg that retained the old L-band receiving equipment were fitted with conversion equipment, which enabled them to receive the S-band signals from the Mariner spacecraft. In addition, the R&D station at the Goldstone Venus site, which by then had acquired a high-power, 100-kW transmitter, was to provide backup for the 10-kW transmitters at the other stations in the event spacecraft problems required a more powerful uplink for commanding purposes.

These first Mars flights also coincided with very significant improvements in the capability and operational management structure of the Ground Communications Facility (GCF) and Space Flight Operations Facility (SFOF) at JPL. The SFOF was a large data-handling machine, albeit housed in a barely finished new building at JPL, where data arriving from the tracking stations was processed in real time and distributed to the DSN and Flight Project Operations Control Groups for action and to Science Groups for analysis. The simple control room of the Ranger and early Pioneer days with a few desks, teletype machines, and display boards was “history.”

Although the first of the Mariner 1964 missions failed due to a launch vehicle problem, the second, *Mariner 4*, was launched successfully on 8 November 1964. A little more than seven months later, it reached Mars. On 14 July 1965, in response to commands from the Johannesburg tracking station, the *Mariner 4* spacecraft turned on its cameras, tape recorders, and scientific instruments in preparation for the first close-up look at Mars. As the encounter point approached, the *Mariner 4* cameras focused on Mars and took a 25-minute sequence of pictures of the Martian surface before the spacecraft trajectory took it behind the planet. The pictures were stored on the spacecraft
tape recorder. Playback to Earth began when the spacecraft came into view of the tracking stations, about an hour later.

It must be pointed out here that although the many millions of data bits in the picture images could be recorded almost instantly by the spacecraft, it would take many days to return the recorded data back to Earth, due to the limited capability of the downlink. The first pictures of Mars took ten days to playback. This would change radically in the years ahead, but at the time of Mariner 4, the downlink capability between Mars and Earth for the 26-m antennas of the DSIF was limited to only 8.33 bits per second.

**Figure 2-3. First close-up picture of Mars. Returned from Mariner 4 on 14 July 1965.** The photograph shows the Phelgra region and Mars horizon from a distance of approximately 10,500 miles.
After a second playback of images and science data, *Mariner 4* continued along its orbit around the Sun, sending back more science and engineering data until the downlink was inadvertently "lost" about two and a half months later.

Scientifically, the mission was judged to be a great success, affording humankind the first close-up views of the Martian surface. Crude as they appear now, those first images, transmitted laboriously at about 8 bits per second over millions of miles of deep space, were hailed with tremendous enthusiasm by the public at large. A composite image of the Phelgra region of Mars, taken by the *Mariner 4* spacecraft, was proudly displayed in the Main Lobby of the Engineering Building at JPL, where for many years, it served both as a reminder of the humble beginnings of the planetary program and as the point from which to gauge the astonishing progress that would take place over the next few years. The original picture is reproduced in Figure 2-3.

For some time after the downlink signal was lost by the DSIF stations, the R&D Venus station at Goldstone continued to search for it. Eventually the signal was recovered and used to check out and calibrate the new 64-meter antenna at Goldstone. It was also planned to use *Mariner 4* in conjunction with *Mariner 5* to perform radio science experiments in interplanetary space from three vantage points: two spacecraft and Earth. However, the spacecraft supply of attitude control gas was exhausted during engineering tests in this extended phase of the *Mariner 4* mission. After three years of operation in space, and 1,119 passes by the DSN tracking stations, the mission was terminated.

**Mariner 1967**

NASA chose to use the 1967 planetary launch window for a second mission to Venus. The spacecraft for this mission would be the one remaining spacecraft from the three that had been built for the 1964 Mars missions. Fitted with a different set of science instruments, including a photometer, radiometer, and plasma probe, the spacecraft would further explore the dense, optically opaque Venusian atmosphere.

The tracking and data acquisition requirements for support of *Mariner 5* were complicated by the DSN desire to involve *Mariner 4*, which had since been recovered, in simultaneous radio science experiments in interplanetary space. In addition, new telemetry and command processing equipment added to the Network, between the *Mariner 4* and *Mariner 5* launches, further complicated the technical and operational interfaces between the DSN stations and the flight project organization at the SFOE. The spacecraft was more complex, too. It carried, in addition to the standard lunar ranging system, a newly developed system of ranging for its first flight evaluation. The Tau system, as
it was called, was designed to extend the DSN ranging capability beyond the limit of the lunar distance.

At Goldstone, Mariner 5 would be supported by the two 26-m stations (Echo and Pioneer) and the new 64-m Mars station. In Australia, it would be Woomera and the new 26-m station at Tidbinbilla that would be used. Johannesburg and another new 26-m station at Robledo, near Madrid, Spain, would complete the DSN support for this mission. At the SFOF, a new 7044 computer system would see its first operational use on Mariner 5 and demonstrate the capability to process Mariner 4 and Mariner 5 data simultaneously, even though the data streams came from different DSN stations. To handle so many data streams from the increasing number of tracking stations, a newly installed communications processor in the SFOF used computer switching to direct all communications throughout the DSN.

Launched on 14 June, the spacecraft was first placed in an Earth parking orbit before being injected into a final trajectory to Venus. Before reaching the limit of its capability, the DSN lunar ranging system followed the spacecraft to a distance of 10 million km, making Mariner 5 the first spacecraft to be ranged beyond lunar distance. The new Tau ranging system was activated about two weeks before success in tracking the spacecraft to the Venus encounter and beyond, to about 75 million km. Together with Doppler and angle data, ranging data became a standard type of radiometric data generated by the DSN and greatly enhanced the orbit determination process for the navigation of future spacecraft. With the downlink running at 8.33 bits per second and encounter activities proceeding smoothly, Mariner 5 made its closest approach to Venus on 18 October 1967, at a range of 3,946 km. The science return satisfied the mission objectives and the DSN continued to track the spacecraft until it passed out of radio range at about 160 million km.

Mariner 1969

In discussing the background to the Mariner 1969 missions Corliss wrote, “Earlier probes to Venus and Mars had indicated that Mars was the most likely planet in the solar system to support life. The richly detailed and cratered surface of the planet revealed by Mariner 4 had surprised planetologists and made them anxious for more photos. Mars thus became NASA's prime planetary target. The Mariner Mars 1969 mission, therefore, concentrated on TV imaging of the planet's surface, and experiments that might aid the design of future missions, particularly those looking for life. Besides the TV cameras, the two new Mariner-type spacecraft assigned to the mission carried an ultraviolet spectrometer, an infrared spectrometer, and an infrared radiometer.”
For the DSN, the Mariner 1969 missions were of special importance because they included the first flight demonstrations of the new DSN high rate telemetry system. Previously, with downlinks limited to just over 8 bits per second, playback of telemetry data from spacecraft at the range of Mars or Venus was measured in days or even weeks. With the DSN’s new block-coded telemetry system running at 16,200 bits per second, roughly two thousand times faster than the former system, low resolution pictures could be sent in real time from Mars. The new high rate telemetry did not replace the existing low rate system. It was an addition to the DSN’s rapidly increasing capability for planetary exploration. Corliss continued, “The DSN was ready for the much greater distances and higher rates required (for planetary exploration). The various technical advances and new facilities just described had begun years before the new missions left their launch pads. As usual though, the new DSN capabilities, which had seemed perhaps unnecessarily ambitious when proposed, were quickly absorbed by the new mission designers.”

Tracking and data requirements for the Mariner 1969 missions (Mariners 6 and 7), included not only the existing 26-m stations, but the new 64-m antenna at Goldstone as well. The downlink would carry telemetry data at either 8.33 or 33.33 bits per second for normal spacecraft operations during the cruise period. When the spacecraft reached Mars, the new high rate telemetry experiment would be turned on. Of course telemetry reception at 16,200 bits per second would be possible only when the spacecraft was in view of Goldstone, where the big 64-m antenna was required to enhance the downlink sufficiently to carry data at this rate.

Orbit determination requirements for the very precise navigation needed to fly the spacecraft close enough for a Mars encounter would be based on standard radiometric data, including an improved version of the Tau planetary ranging system.

Both Mariners 6 and 7 were launched successfully in February and March 1969. For the first time, NASA had successfully launched a pair of spacecraft. Both spacecraft were on target and, from a DSN viewpoint, both were in the same part of the sky. This meant that both spacecraft would be in view of a given DSN site, although not within a single antenna beamwidth, simultaneously. Tracking both spacecraft simultaneously required two antennas and two telemetry data processors, one for each downlink. At the same time, there were the Pioneer spacecraft and backup support for the first Apollo missions to be considered as well. The “loading” on the DSN antennas had begun to reach the point of saturation, and the resource allocation system was hard pressed to service all of its customers.
As Mars began to draw near towards the end of July, encounter operations began with Mariner 7 only five days behind Mariner 6. Corliss describes what happened next. “All seemed to be going well until about six hours before the Mariner 6 encounter, when Johannesburg reported that the signal from Mariner 7 had disappeared. It was an emergency that came at the worst possible time. The Robledo, Spain[,] antenna discontinued its tracking of Pioneer 8 and began to search for the lost spacecraft. When Mars came into view for Goldstone, the Pioneer 26-m antenna joined the search, while the Echo 26-m antenna continued tracking Mariner 6. It was decided to send a command to Mariner 7 to switch from the highly directional high-gain antenna to its omnidirectional low-gain antenna. The spacecraft responded correctly, and suddenly both the Pioneer station and the Tidbinbilla station began receiving low-rate telemetry from the recovered spacecraft. Something had happened to the spacecraft but no one knew just what.”

While the DSN was committed to support one Mariner at a time in a mission-critical phase, this situation presented one spacecraft approaching encounter and a second one with a serious and unknown problem. To deal with it, the DSN applied its main effort to the ongoing Mariner 6 encounter, while a special team at JPL studied the Mariner 7 anomaly.

Fortunately, the Mariner 6 encounter events executed without any problems. Many pictures of Mars were taken and successfully returned to Earth using both the high-rate and normal low-rate telemetry systems. The special “Tiger Team” at JPL was able to overcome the Mariner 7 attitude problem by using the real-time high-rate telemetry sight, the TV cameras on Mars, in time to carry out a very successful encounter.

For both encounters, the new High-Rate Telemetry System (HRT) proved its worth, not only in recovering from the Mariner 7 emergency, but also in providing a much faster channel for playing back TV and other high-rate science from Mars to Earth. In all, 202 pictures covering almost 20 times the area covered by Mariner 4 were returned to Earth by the Mariner 6 and 7 missions.

Following the formal end of the mission in November 1969, both spacecraft, still operating perfectly, were used to perform radio science experiments in relativity, astronomical constants, and electron densities in interplanetary space.
Mariner 1971

We turn again to Corliss for a view of these missions: “The logical follow-on mission to Mariner-Mars 1969, using the lunar program analogy, would be picture-taking orbiters around Mars. The next Mars opportunity was in the spring of 1971, and two Mariner-class spacecraft were prepared accordingly. The new Mariners drew heavily upon the technology of the 1969 mission. Instrumentation was very similar, with emphasis again on photography. The primary objectives were the search for evidence of life and the gathering of data that would aid Mars landers. After mapping as much of the surface as possible, scientists wanted more data on the density and composition of the Martian atmosphere. A 90-day orbital mission for each spacecraft was planned. These spacecraft would be the first terrestrial satellites of another planet.”

The requirements levied upon the DSN for these missions were even more extensive than those of the 1969 missions. This was due to the precise navigation and maneuvers needed to inject the spacecraft into orbit around Mars and to the DSN antenna coverage required for 90 days of orbital operations for two spacecraft simultaneously.

During the intervening two years between the Mars opportunities, DSN capabilities expanded considerably. The Multimission Telemetry System had been inaugurated on the 1969 flights, and for the 1971 mission. The experimental HRT, which had been demonstrated so successfully in 1969, was fully operational. Pictures and science could be transmitted back from Mars to Goldstone much more rapidly. A 50,000 bit per second wideband communications link was available to carry two 16,200 bits per second (16.2 kbps) data streams simultaneously between Goldstone and JPL. In effect, the DSN now had a downlink capable of delivering two simultaneous 16.2 kbps data streams directly from Mars to JPL in real time. Of course the Mars station at Goldstone was the only 64-m antenna in operation at that time, but the high speed readouts of the Mariner 71 tape recorders were planned to take place only when DSS 14 had Mars in its view. Another important capability of the DSN, which was planned for use on these missions, was the ability of a single DSN antenna to simultaneously handle two spacecraft located in the same beamwidth.

The Mariner 71 flights began inauspiciously with a failure of the upper stage (Centaur) of the Atlas-Centaur launch vehicle which resulted in the loss of Mariner 8. Investigation of the Centaur problem delayed the next launch to 30 May when Mariner 9 lifted off on a direct ascent trajectory for Mars with an arrival in mid-November 1971. Although the loss of one spacecraft placed the burden of
responsibility for the entire mission on Mariner 9, it reduced the burden of tracking for the DSN to a single spacecraft.

After a perfect midcourse maneuver in June and a nominal cruise to the planet, Mariner 9 was injected into Mars orbit on 14 November. Unfortunately, just at the time of Mariner 9’s arrival, the planet was covered by a huge dust storm, which precluded any useful photography. Mariner 9 continued to make its regular 12.567 hour orbits while the scientists waited for the dust to settle. While the spacecraft waited in orbit, the other instruments were busy and pictures of Mars’s moons Phobos and Deimos were taken.

By 3 January 1972, the dust storm had cleared sufficiently for the 90-day mission to begin. Soon, the pictures came by the thousands to reveal, for the first time, deep fluvial channels, possibly cut by water, and evidence of ice action in the polar regions. Detailed maps of the Martian surface, needed to plan the Viking landings to come a few years later, were being drawn even as the Mariner 9 cameras covered more and more of the surface of the planet.

Because the spacecraft was still operating so well at its nominal end date in April, NASA extended the mission to re-examine some specially interesting areas and observe solar occultations as the spacecraft moved through the shadow of Mars twice per day. Despite its rigorous and longer than planned mission, Mariner 9 survived until 27 October 1972.

Mariner 1973

The launching of Mariner 10 in November 1973, on the first mission to Venus and Mercury, marked the end of the Mariner spacecraft era. Immensely successful as it was, the Mariner 1973 Venus-Mercury mission was the last to use the so-called Mark III-73 network model which had supported the previous Mariner missions to Mars in 1969 and 1971 and the later Pioneer missions to Jupiter.

High-rate telemetry, wideband communication circuits connecting all complexes to JPL, and 64-m antennas at all three sites formed the basis for the DSN support of the Mariner 10 mission. However, the spacecraft carried a redesigned imaging system that required the DSN to provide a downlink capability from Mercury of 117.6 kbps to fully exploit the new imaging system capability. This data rate greatly exceeded the operational capability of the existing DSN high rate telemetry system of 16 kbps.

Responding to pressure from the Project, the DSN had proposed a substantial number of improvements to the existing DSN downlink capability to increase the mission data
return and enhance its science value. These improvements included 1) the installation of a developmental supercooled maser and ultra cone at DSS 43; 2) the installation of an S/X-band dichroic plate and feed cones at DSS 14; 3) the implementation of a special 230-kbps wideband data transmission circuit from Goldstone to JPL for real-time picture transmission and a 28.5-kbps circuit from Australia and Spain to JPL for transmission of recorded data; 4) the redesign of the telemetry and command processor (TCP) computer software to handle the data rates as high as 117 kbps; and 5) the installation of a Block IV receiver-exciter at DSS 14 for the S/X-band Radio Science Experiment.

As the mission extended into a second encounter with Mercury in 1974, the increasing Earth-spacecraft range introduced further losses into the telecommunication path. To compensate for this additional loss, the DSN implemented a new signal enhancement technique, previously developed and demonstrated by Spanish engineers at the Madrid Complex in 1969 and 1970. In this technique, the spacecraft signals from several DSN stations were added together at a central point so that their combined signal strength would be greater than that of a single station. The new “antenna arraying and signal combining” technique was implemented, this time at Goldstone, using stations DSS 14, DSS 12, and DSS 13. Tests with the spacecraft demonstrated an improvement in downlink performance of 0.7 dB. In September 1974, the new technique was used for the first time by the DSN, with good results, as a fully operational capability to support the second Mariner 10 Encounter of Mercury.

The Mariner 10 data return statistics were impressive. At its conclusion, it had returned to Earth over 12,000 images of the planets Venus and Mercury. In terms of scientifically useful pictures, this exceeded the combined total of the Mariner 6 and 7 missions to Mars by a factor of almost 15.

The time Mariner 10 had spent in deep space, short though it was, had been very eventful. Years later, Bruce Murray, who at the time was leader of the Mariner 10 Imaging Team, expressed his view of the scientific worth of the mission, “The economy class Mariner flyby of Venus and Mercury was one of the most productive space science experiments ever carried out.”

On 24 March 1975, shortly after its third flyby of the planet Mercury and exactly 506 days after its launch in November 1973, the last of the Mariner series of planetary spacecraft fell silent. With its attitude control gas supply exhausted, Mariner 10 started to slowly tumble out of control, and controllers at the Jet Propulsion Laboratory in Pasadena, California, sent a command to turn off its transmitter to avoid contaminating the deep space environment with an unwanted source of radio emissions.
From the DSN point of view, the *Mariner 10* Mission to Venus and Mercury was associated with a long list of “firsts.”

The *Mariner 10* mission was the
- first multiplanet gravity assist mission,
- first spacecraft to photograph Venus,
- first spacecraft to fly by and photograph Mercury,
- first spacecraft to have multiple encounters with a target planet,
- first JPL spacecraft to transmit full-resolution pictures in real time from planetary distances,
- first mission to use dual-frequency radio transmission, and
- first mission to use arrayed ground station antennas to improve signal-to-noise ratio.

For the DSN, the *Mariner 10* mission to Venus-Mercury provided a fitting conclusion to the Mariner Era. During that era, there had been many other important missions sharing the attention of the DSN, which will be discussed later. Nevertheless, it was the Mariners that influenced the future capabilities of the DSN for the longest time and in the most significant way, as is evident in the summary of the Mariner missions contained in the following table (on the following page).

**Pioneer Interplanetary Missions**

Unlike the short missions of the five earlier Pioneer lunar probes, the second generation of Pioneer spacecraft consisted of long duration missions designed to measure the interplanetary fields and particles environment along trajectories that placed the spacecraft in heliocentric orbits ranging between 0.7 and 1.2 AU. They were sometimes described as interplanetary weather stations. The four spacecraft, *Pioneers 6–9*, were each launched approximately one year apart, starting in December 1965 with *Pioneer 6* and ending in November 1968 with *Pioneer 9*.

All four spacecraft transmitted continuous streams of scientific data from various orbits around the Sun. This meant that the DSIF was required to provide almost continuous tracking for first one, and eventually four Pioneers, to ensure that all of the rapidly changing science data were captured. Furthermore, instead of dying after the first year or so of operation as was expected, all four Pioneers continued to operate actively in deep space for many years. At the end of the Mariner Era they were still going strong and had become a permanent feature of the DSIF routine tracking schedules.
Summary of the Mariner Planetary Missions: 1962–73

<table>
<thead>
<tr>
<th>Mission, Launch Date</th>
<th>Objective Result</th>
<th>Science Return</th>
<th>Max. Data Rate at Encounter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, Venus, Jul 62</td>
<td>Flyby, Failure</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>2, Venus, Aug 62</td>
<td>Flyby, Success</td>
<td>Scanned Venus surface at encounter</td>
<td>8.33 bits/sec</td>
</tr>
<tr>
<td>3, Mars, Nov 64</td>
<td>Flyby, Success</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>4, Mars, Nov 64</td>
<td>Flyby, Success</td>
<td>First close-up photos of Mars surface</td>
<td>8.33 bits/sec</td>
</tr>
<tr>
<td>5, Venus, Jun 67</td>
<td>Flyby, Success</td>
<td>Science data on Venus surface environment</td>
<td>16.33 or 8.33 bits/sec</td>
</tr>
<tr>
<td>6, Mars, Feb 69</td>
<td>Flyby, Success</td>
<td>High-res. photos of Mars equatorial region</td>
<td>16,200 bits/sec</td>
</tr>
<tr>
<td>7, Mars, Mar 69</td>
<td>Flyby, Success</td>
<td>High-res. photos of Mars southern hemisphere</td>
<td>16,200 bits/sec</td>
</tr>
<tr>
<td>8, Mars, May 71</td>
<td>Orbiter, Failure</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>9, Mars, May 71</td>
<td>Orbiter, Success</td>
<td>Mapped whole Mars surface photos and data from Mercury</td>
<td>16,200 bits/sec</td>
</tr>
<tr>
<td>10, Venus/Mercury, Nov 73</td>
<td>Flyby, Orbiter, Success</td>
<td>UV photos of Venus, close-up photos and data from Mercury</td>
<td>117,600 bits/sec</td>
</tr>
</tbody>
</table>

The new Pioneer program was directed by the NASA Ames Research Center (ARC) at Mountain View, California, and thus it became the first major non-JPL or “off-Lab” flight project to require support from the DSIF. In addition, ARC wanted to exercise mission control functions from Mountain View rather than from the mission control center at JPL in Pasadena. These and other requirements, related to enhanced downlink capability, presented a new situation for the DSN and forced it into broadening its management structure to deal with flight projects other than those directed by JPL. In due course, special positions were created in the DSN Office to deal with the unique requirements of each new flight project. This unique position was given the title of “DSN Manager for Project . . . .”
Like other flight projects in these early years, the Pioneer Project provided the tracking stations with a set of unique Ground Operational Equipment (GOE) for use when the station was tracking its particular spacecraft. The stations were obliged to take on the onerous tasks of accommodation, installation, maintenance and operation. The GOE provided real-time telemetry data processing and spacecraft commanding functions, which could not be handled by the existing DSIF equipment because the Pioneer spacecraft design differed from that of the current JPL spacecraft. Eventually, the Madrid engineering staff developed new software for the DSN’s Multiple Mission Telemetry and Command Processor that emulated the GOE functions and interface signals, thereby avoiding the need for the special Pioneer-unique equipment in the Network.

For the most part, the DSIF used the network’s 26-m antennas to support the Pioneer missions. However, as the Pioneers reached the threshold of detection capability for the 26-m antennas, improvements in downlink sensitivity became necessary to the continued life of the missions. DSN engineers made systematic improvements in the S-band maser sensitivity, microwave equipment, and receiver “tracking loop” performance and advanced demodulation hardware, while Madrid engineering staff developed special convolutional decoding software for Pioneer 9. As a result of these improvements, the threshold of performance for Pioneer on the 26-m antennas was extended from 0.4 AU in 1965, to 1.5 AU by 1969. Although it was driven by the enduring performance of the Pioneers, the improved downlink capability was, of course, of great benefit to later missions and the to the DSN in general.

Inevitably, as the Pioneers moved steadily deeper into space, the strength of their downlink signals dropped below the detection capability of the enhanced 26-m antennas. Now, fully compatible with the Network’s multiple mission capabilities, the Pioneer spacecraft were transferred to the new 64-m antennas which were, fortuitously, just coming into service in the network. With the great increase in downlink capability that the 64-m antennas brought to the Network, the communication range of the Pioneers was extended significantly into, and even beyond, the next era.

**Pioneer Jupiter Missions**

Much smaller than the JPL-designed Mariner-class spacecraft, the interplanetary Pioneers were simple and rugged and, being spin-stabilized, avoided the complexities of three-axis attitude control used by the Mariners. The efficacy of their design had been amply demonstrated by four years of continuous deep space operation when, in 1969, NASA selected the “third generation” Pioneers for the first missions to Jupiter.
Although the Jupiter Pioneers were technically more advanced than the previous spacecraft, the design philosophy was much the same. This project was directed as before, by ARC.

The spacecraft were instrumented to carry out fields and particles measurements throughout the entire mission. At Jupiter they were to explore the Jovian system, obtain the first spin scan images of the planet, and investigate its enormous magnetosphere. To test new technologies for future missions into this previously unexplored region of deep space, where sunlight was too weak for satisfactory operation of solar cells, the spacecraft were powered by Radioisotope Thermal Generators (RTGs). Instead of a mast-type of antenna, the new Pioneers carried 2.75-m parabolic dish antenna for communications with the DSN. They were, for their time, very advanced spacecraft.

*Pioneer 10* finally left the launch pad on 3 March 1972, and made its closest approach to Jupiter 21 months later, on 4 December 1973, at a distance equal to 2.86 Jupiter radii, 302,250 km from the center of the planet. Science data from the encounter instruments confirmed the complexity of the Jupiter system. For the first time, close-up photos of the planet surface were obtained and an atmosphere was detected on the satellite Io. The giant planet’s magnetosphere was found to be disk shaped and bigger than the Sun itself.

DSN support for the *Pioneer 10* Jupiter mission was complicated by serious conflicts for the 26-m and 64-m antennas by the *Mariner 10* mission to Mercury and Venus and by the need for Goldstone 64-m radar surveillance of possible Viking-Mars landing sites. The multiplicity and complex nature of these overlapping view periods presented the DSN with a problem it had not encountered up to this time, but which loomed ominously in the years ahead. A Network Allocation Working Group was established to resolve the conflicts by mutual compromise between the conflicted projects. The DSN had moved from an age when it could assign antennas for the exclusive use of a single flight project to an age when it would be necessary to assign missions to antennas on a day to day, or even hour to hour, basis. Thus was born the DSN scheduling system, which soon became a permanent feature of daily DSN activity.

By the close of the Mariner Era, eleven DSN stations had provided 2000 tracking passes for *Pioneer 10* between April 1972 and January 1974, the equivalent of 21,000 hours of tracking time. During this time the spacecraft distance from Earth varied from 22 million to 890 million kilometers. During the 60-day Jupiter encounter period, over 17,000 commands were sent to control the complex spacecraft sequences.
Except for a sling-shot (later called a gravity-assist) encounter with Jupiter, the Pioneer 11 mission was essentially the same as that of Pioneer 10. It was launched on 6 April 1973 and reached Jupiter at the end of the year.

Building on the success of the Pioneer 10 encounter with Jupiter, the ARC mission controllers retargeted Pioneer 11 in flight in such a way that, at its encounter with Jupiter in December 1973, trajectory was altered to eventually intercept the ringed planet Saturn. Pioneer 11 went on to pass within 20,000 kilometers of Saturn’s main outer ring system on 1 September 1979, and became the first spacecraft to do so. The remarkable success of Pioneer 11, discussed further in the chapter on the Voyager Era, paved the way for the Voyager spacecraft to later pass Saturn.

Surveyor Lunar Lander Missions

Originally the objectives of the Surveyor Lunar Lander program, complemented by Lunar Orbiters, were primarily scientific in nature. After Apollo became a national goal, the objectives of the Surveyor program were redirected somewhat towards determining whether a human could land safely on the surface of the Moon. The Surveyor program was managed by JPL and controlled from the Space Flight Operations Facility (SFOF) which had replaced the simple mission control center of the early days.

The DSN felt the impact of Surveyor in a number of ways. These stemmed from a new (to the DSN) concept that Surveyor planned to use to control its spacecraft once they landed. The spacecraft had few automatic features and depended almost entirely on real-time commands for its operation on the lunar surface. This concept of interactive control of a distant spacecraft was based on real-time video and other data displays of the current state of the spacecraft. These data would be used by spacecraft controllers to make decisions regarding the desired future state of the spacecraft. Commands transmitted from the DSN stations would control the actions of the spacecraft accordingly. To make this possible, video data streams from the tracking stations, 4,400 bits per second from Goldstone, 1,100 bps from the overseas stations, were first transmitted via the Ground Communications circuits to the SFOF. There the data was converted to television displays for operational decisions by the spacecraft controllers, and to photographic images for scientific interpretation by the project scientists.

Obviously this level of operational decision making was completely dependent upon the reliability of the communications circuits between the DSN sites and JPL. To ensure the integrity of the overseas communication circuits for Surveyor, all DSN traffic was, for the first time, carried on a high-quality satellite channel provided by NASCOM.
As was the case for Pioneer, the Surveyor Project provided special mission-dependent equipment in the form of a Command and Data Console (CDC), for installation at each of the DSN stations, that would support the missions. The CDCs were operated and maintained by project people who were resident at the stations, pending the transfer of responsibility to the DSN. In the event of a loss of communications between a DSN station and mission control at the SFOF, these personnel would be capable of controlling the spacecraft to ensure its safety until the situation was corrected.

In the period prior to launch of the first Surveyor, lengthy and elaborate simulations were carried out to prepare the DSN and Surveyor operations teams for the scenarios they would likely face in interacting with the spacecraft on the lunar surface.

Using its new Atlas-Centaur launch vehicle, NASA launched seven Surveyors between May 1966 and January 1968. The success of all seven launches demonstrated the reliability of the new high-energy Centaur upper stage, a potent liquid-hydrogen-fuelled booster rocket which had recently been developed at NASA’s Lewis Research Center. The Centaur subsequently came into general use as an upper stage for deep space mission launches, until the program was discontinued in 1986 as a consequence of the Space Shuttle Challenger disaster.

Landing sites for the Surveyor spacecraft had been chosen primarily for their interest to the future Apollo program and four of the spacecraft soft-landed successfully at, or near, these sites and returned large quantities of engineering and scientific data. Two of the spacecraft failed to reach the lunar surface. Surveyor 7, the final spacecraft of the series, was targeted to land in the more scientifically interesting lunar highlands. After a successful landing it demonstrated the advantages of real-time control and manipulatory capability by carrying out a number of experiments that involved digging trenches, moving rocks, and even recovering an alpha-scattering experiment that had failed to deploy correctly after touchdown. The effort that went into the pre-launch simulation efforts clearly proved to be worthwhile.

Despite the complexity of the Surveyor program, DSN support for all seven flights was deemed to be excellent due in no small measure to the exhaustive testing and training program that preceded the first launch. The table below, which summarizes the data returned from each of the Surveyor missions, attests to the quality of the DSN data retrieval support.
Summary of Surveyor Lunar Lander Missions

<table>
<thead>
<tr>
<th>Mission</th>
<th>Launched</th>
<th>Spacecraft Operations on the Lunar Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>1; 1966; 30 Mar</td>
<td>Soft landing, operated for 2 lunar days. Returned 13,000 pictures, received 108 commands.</td>
<td></td>
</tr>
<tr>
<td>2; 1966; 20 Sep</td>
<td>Spacecraft became unstable, destroyed itself in flight.</td>
<td></td>
</tr>
<tr>
<td>3; 1967; 17 Apr</td>
<td>Soft landing, operated for 1 lunar day. Returned 10,000 pictures, received 63,000 commands.</td>
<td></td>
</tr>
<tr>
<td>4; 1967; 14 Jul</td>
<td>Lost radio contact touchdown.</td>
<td></td>
</tr>
<tr>
<td>5; 1967; 11 Sep</td>
<td>Soft landing, operated for 2 lunar days, 118 hours of alpha-scatter experiments. Returned 27,000 pictures, received 123,000 commands.</td>
<td></td>
</tr>
<tr>
<td>6; 1967; 7 Nov</td>
<td>Soft landing, operated for 1 lunar day, 30 hours of alpha-scatter experiments. Returned 45,000 pictures, received 170,000 commands.</td>
<td></td>
</tr>
<tr>
<td>7; 1968; 7 Jan</td>
<td>Soft landing, operated for 1 lunar day, 100 hours of alpha-scatter, many surface sampler experiments. Returned 28,000 pictures, received 150,000 commands.</td>
<td></td>
</tr>
</tbody>
</table>

Note: One lunar day is equivalent to approximately 27 Earth days.

Lunar Orbiter Missions

Although an orbital lunar mapping mission had been originally conceived by JPL as an adjunct to the Surveyor lander program, NASA eventually assigned the development and management of the Lunar Orbiter project to the Langley Research Center in Hampton, Virginia.

The main objective of the Lunar Orbiter project was to obtain high-resolution photographs of potential Apollo landing sites on the Moon to complement those made by Surveyor on the actual surface. From its continuous orbit about the Moon, it would also make a detailed photographic survey of the entire lunar surface. To accomplish this task, the spacecraft carried a complex wide-angle camera and film processing package which employed facsimile transmission techniques to return the images to Earth via the tracking stations of the Deep Space Network. There were five identical spacecraft in the Lunar Orbiter program, all launched on Atlas-Agena vehicles in one year, beginning August 1966. All five missions were successful. Each of the missions orbited the Moon at a different inclination to the lunar equator and was therefore able to scan a different section of the lunar surface. The combined result of all five missions amounted to a sur-
vey of almost 99 percent of the entire lunar surface. By the time the project ended, Lunar Orbiter had surveyed the entire front surface of the Moon and most of the back surface, in some 2,000 individual high-definition, photographic images.

A standard S-band network of three deep space tracking stations was used to support the five Lunar Orbiter missions. Like the Pioneer and Surveyor projects, the Lunar Orbiter project provided these stations with special purpose mission-dependent ground reconstruction equipment (GRE), as well as personnel to operate them. The Lunar Orbiter missions were conducted concurrently with the Surveyor and Mariner-Venus missions. This multiple-mission environment heavily taxed the resources of the DSN and, by requiring precise scheduling of the activities of all three projects and a high degree of cooperation and coordination between them, presaged the later establishment of the Network Resources Allocation Working Group.

The Lunar Orbiter missions provided the DSN with the first opportunity to evaluate its new “turnaround” lunar ranging system in actual flight operations. Prior to this time, Earth to spacecraft range had been estimated by electronically processing the Doppler tracking data, a method that was cumbersome and prone to errors from “slipped cycles.” The Lunar Orbiter spacecraft carried a ranging transponder, which, after detecting a special code carried on the uplink, would retransmit the code along with telemetry data on the downlink back to Earth. At the DSN tracking station, special ranging equipment compared the downlink code with uplink code to calculate the time it took the range code to travel out to the spacecraft and back. After proper calibrations and corrections were applied, spacecraft navigators used these data to obtain a very precise value for the spacecraft range (distance between tracking station and spacecraft). So successful were these inflight demonstrations that turnaround ranging, in various more refined forms, soon came into regular use along with Doppler data as the standard types of radiometric data generated by the DSN for all lunar spacecraft navigation purposes.

In addition to refining the new turnaround ranging system, DSN engineers extended its use to improve the time synchronization between DSN stations throughout the world. This enabled a more accurate determination of the spacecraft orbit about the Moon, which in turn yielded more and better information about the geophysical properties of the Moon itself. In addition to purely scientific interest, these data also provided valuable background information for the design of the Apollo piloted missions to the Moon, which were about to begin.

After the Lunar Orbiter program ended, scientists at JPL continued to analyze the wealth of DSN ranging and other radiometric data that had been generated during the Lunar
Orbiter missions. The outcome of this work greatly improved our understanding of the radius, orbit, and gravitational field of the Moon. It also led to the discovery of hitherto unknown anomalies in the lunar gravitational field due to unexpected concentrations of mass, or "mascons" as they came to be called, lying beneath the lunar surface.

**Apollo Missions**

Just as NASA had assigned tracking and data acquisition responsibility for the planetary program to JPL, it assigned tracking and data acquisition responsibility for the Apollo program to the Goddard Space Flight Center (GSFC), Greenbelt, Maryland. And, just as JPL built the DSN for its planetary program, GSFC built the Manned Space Flight Network (MSFN) for supporting Apollo. The MSFN comprised two types of tracking networks. The first consisted of a large number of 9-m stations to handle the Apollo spacecraft during Earth-orbit operations, while the second network consisted of three 26-m stations to handle the translunar and lunar phases of the flights. For obvious reasons, the 26-m stations of the MSFN were located near the DSN stations at Goldstone, Canberra, and Madrid.

Although the MSFN provided the prime network for tracking and data acquisition support for the Apollo flights, the DSN also contributed a great deal of technology and facility support to Apollo. The DSN provided the MSFN with S-band receiving, transmitting and ranging equipment and computer software for lunar trajectory orbit determination purposes. Also, because the MSFN stations were (intentionally) very similar in design to the DSN stations, it was decided to equip one DSN station at each longitude (DSS 11, DSS 61 and DSS 42) with sufficient MSFN equipment to act as backup for the prime MSFN 26-m stations at the same site, or one nearby. These became known as the "mutual" stations. Corliss has described this aspect of the JPL/DSN role in Apollo in his account of the history of the Piloted Space Flight Network (MSFN).

A second control room called the MSFN wing was added to each DSN station and connected via a microwave link to the nearby prime Apollo station. The MSFN wing housed the special Apollo transmitting and receiving equipment, the MSFN electronics and recorders, and the switching connections that allowed the single DSN 26-m antenna to be used for tracking either deep space or Apollo spacecraft.

By mutual agreement between JPL and GSFC, Apollo mission operations at both the DSN mutual station and the MSFN prime station were directed by a single coordinator provided by the MSFN at each complex. This operational arrangement proved to
be so effective that it was used without change for all the Apollo flights, beginning with the Apollo 4 test flights in 1967 until the program concluded with Apollo 17 in 1972.

Following the success of the early test flights, DSN support for the Apollo program expanded to include the Goldstone 64-m antenna as backup for special events and emergencies. To make this possible, equipment was added to the receivers at the 64-m antenna to allow the Apollo downlink signals to be transferred several miles via microwave link to the prime MSFN station for processing and onward transmission to the Apollo Mission Control Center in Houston. Furthermore, during Apollo tracks, the 64-m antenna would have to be driven by computer generated pointing data derived from Apollo spacecraft trajectory information provided by the MSFN.

These new interfaces, implemented and tested in great haste, were completed just in time for the first piloted lunar orbit flight on Apollo 8 in 1968. The then new 64-m antenna at Goldstone was called upon to provide backup support for the 26-m MSFN antennas for receiving television signals for public broadcast while the spacecraft was en route to and from the Moon and in orbit around the Moon. The arrangement worked perfectly, and from then on the Goldstone 64-m antenna was used on a regular basis to provide critical and, in some cases, emergency (Apollo 13) support for all Apollo missions.

Apollo 13 was the third piloted mission with the Moon as its destination, and a landing and return to Earth as its objective. The mutual stations of the DSN, together with the big Mars antenna (DSS 14) at Goldstone, had been scheduled to provide the backup coverage for the MSFN prime stations as was normal practice by the time of Apollo 13.

After the Saturn V launch from Cape Kennedy on 11 April 1970, the mission proceeded "nominally." The DSN stations commenced to follow the detailed tracking schedule developed to minimize impact to the Mariner 1969 Mars spacecraft, then in its extended mission. All went well until Apollo 13 was making its third pass over Goldstone on 14 April. At that point, about 55 hours into the mission, the unthinkable happened—the explosion in an onboard oxygen tank rendered the Lunar Service Module, with all its redundant systems, useless. All mission objectives, except return to Earth, were abandoned. While the mission controllers at Houston set about trying to recover the crew, all tracking stations were placed on high alert for the spacecraft emergency. The Goldstone Mars antenna was immediately requested to extend its tracking coverage of the current and all subsequent Apollo 13 passes, to the maximum possible, horizon to horizon.

The unique capabilities of the 64-meter antenna were about to be demonstrated once again. To conserve electrical power, the spacecraft began transmitting with low power.
through its low-gain omnidirectional antenna, an emergency procedure which resulted in a much weakened downlink. Because of its great receiving capability, DSS 14 was the only tracking station able to maintain contact with the disabled spacecraft and its crew during many parts of the aborted mission. Even when the 26-meter stations were able to receive the downlink, the improved clarity of the astronauts' voice channels when DSS 14 came into view was of great assistance and encouragement to those in danger during the subsequent recovery efforts.

After the astronauts were safe and the mission concluded, the DSN received the following appreciative message from the director of flight operations at Houston. “We wish to commend the entire Network for their superior performance in support of Apollo 13. In the midst of this most difficult and critical mission, it was extremely reassuring to have a Network with so few anomalies and one which provided us with urgently needed voice and data to bring the crew back safely. We thank you for your outstanding support.” Cognizance of the mutual stations passed to the DSN at completion of the Apollo program in 1972, and much of the electronics technology from the wing stations was subsequently incorporated into DSN systems.
THE DEEP SPACE INSTRUMENTATION FACILITY (DSIF)

When the Mariner Era opened in 1961, the network, then known as the Deep Space Instrumentation Facility (DSIF), consisted of three stations—one at Goldstone, California; another at Woomera, Australia, in the desert 320 kilometers north of Adelaide; and a third near Johannesburg, South Africa. In addition to its 26-m diameter dish antenna, each station had receive and transmit capabilities at a frequency of 960 MHz (L-band), and could process and record telemetry data at low data rates from the JPL-designed space probes. Telephone and teletype circuits linked each site to a simple control and coordination center at JPL. These circuits were carried between continents via undersea cable, and by land line, or in the case of Johannesburg, by a high-frequency radio link, to their ultimate destination.

At that time, the loose organizational structure of JPL allowed for a great deal of interaction between the technical groups responsible for the spacecraft and its operation, and the groups responsible for the development, implementation, and operation of the DSIF. This was of prime importance in the area of telecommunications, where it was essential that the spacecraft radio system was designed to be compatible with the radio systems installed at the tracking stations. While the spacecraft and tracking station design groups each focused on their individual design issues, important questions of “telecommunications compatibility” were responded to, informally, by the engineers involved. It was a carryover from earlier times, when the spacecraft radio and DSIF radio systems had been designed and built in the same technical division at JPL. This situation soon changed, however, and the question of telecommunications compatibility, with all its ramifications, became a major concern at JPL as the NASA space program gathered momentum.

Mission Operations was another factor that dominated the planning processes for early deep space missions. Determining and controlling the flight path of a spacecraft, displaying and analyzing the engineering and scientific data received from it, selecting and issuing commands to the spacecraft, and coordinating the activities of the worldwide stations of the DSIF and the communications links connecting them to JPL, are all part of Mission Operations. This specialized activity is conducted in a central location called the Flight Operations Control Center.

As early as 1960, JPL had completed studies for a facility that could handle mission operations not only for the forthcoming Ranger mission, but also for all future space missions. Plans called for a Space Flight Operations Facility consisting of the equipment, computer programs, and groups of technical and operations personnel that would carry out these and all other functions required to fly the Ranger missions. The facility would
be located in a single building at JPL, and the same teams would work each of the missions to ensure continuity of experience and expertise.

In the short time available before the first Ranger launch, a temporary facility was established next to the existing computer room. Blackboards and pinboards to post current flight status lined the walls, desks, phones, calculating machines, and teletype machines stood wherever space permitted. Later, a few console displays were added for closed circuit television display of printouts from the large mainframe IBM 7040 computers in the adjacent computer room. A large static display board showed the status of the DSIF stations and the communications links between them.

When it became obvious that the makeshift facility would be inadequate even for missions in the immediate future, planning and funding for the much larger permanent facility was accelerated. Designed specifically for spaceflight operations, the Space Flight Operations Facility (SFOF) was completed and began supporting flight missions in 1964. A separate control center for directing the expanded operational functions of the Network occupied a large portion of the new SFOF as shown in Figure 2-4.
The Facility (DSIF) Becomes the Network (DSN)

In a memo to senior staff dated 24 December 1963, the Director of JPL, William H. Pickering, redefined the responsibilities of the DSIF to include “all mission-independent portions of the Space Flight Operations Facility,” in addition to the existing responsibility for the tracking stations, the communications system linking them to JPL. The combined organizational structure was named the Deep Space Network (DSN) and would be directed by Eberhardt Rechtin, with the functional title of assistant laboratory director for tracking and data acquisition.

L-band to S-band

At this time also, a most significant engineering change was being made in the DSN. It concerned the change to a higher operating frequency for the uplinks and downlinks. Mainly as a matter of convenience and expediency, the original receivers and transmitters in the DSN had been designed in 1957 and 1958 to operate at a frequency of 960 MHz. In telecommunications terminology, 960 MHz lies within a narrow band of frequencies identified as L-band. The Ranger spacecraft radio system had to match that frequency to be compatible so that it too operated at L-band. However, there are significant advantages to the uplink and downlink performance to be had from operating at a much higher frequency of 2,200 MHz, or S-band.

By 1963, the availability of new radio frequency amplifiers and transmitters, which would operate well at S-band, allowed the DSN to take advantage of the better uplink and downlink performance at the higher frequencies. With an eye to the requirements of future missions, the DSN set about converting all the tracking stations from L-band to S-band. But where would that leave the Ranger program about to restart its lunar flights, and how would it affect the recently approved Mariner missions to Mars?

The solution devised by DSN engineers was to install S-band to L-band conversion equipment at the stations in parallel with the older L-band equipment. This would accommodate the remaining four Rangers and the first two Mariner missions to Venus on L-band. It could also provide for the later Mariner missions to Mars and the proposed Surveyor missions, both of which would use the more efficient S-band uplinks and downlinks. The L/S-band converter would remain in place until the end of the L-band missions, by which time a new, fully S-band system would be in place. The L/S-band converters would then be removed and the conversion to the more efficient S-band operation would be complete. All missions from then on would be on S-band. Of all the improvements in the early years of the DSN, the move to S-band was probably the most significant.
Improvements for the Mariner Mars Missions

The Mariner 1964 Mars missions were the first in which the DSN would use the newly implemented L/S-band capability to adapt the spacecraft S-band downlink to suit the existing DSN L-band receivers. The capability to send commands to the spacecraft would be provided by 10-kW transmitters recently installed at Goldstone-Pioneer, Johannesburg, and Woomera stations.

In addition to the uplink/downlink improvements accruing from the change to S-band, significant improvements to navigation accuracy were expected from the introduction of atomic clocks throughout the DSN to replace the less stable crystal controlled oscillators. These rubidium frequency standards improved the quality of the radio Doppler data provided to the spacecraft navigators by the DSN stations, enabling them in turn to improve the trajectory determination process necessary to deliver the spacecraft to a small aim point in the vicinity of Mars.

Improvements in the NASA ground communications system (NASCOM), which connected the far-flung stations of the DSN to the Flight Control Center at JPL, had already taken place. Teletype links, voice, and high speed data circuits using a worldwide network of microwave links, and undersea cables and radio circuits were connected to a central communications center at the NASA Goddard Space Flight Center in Greenbelt, Maryland. From there the circuits could be distributed to JPL and other NASA Centers scattered throughout USA, as required. The DSN could call on NASCOM to bring up the communications necessary to support a particular mission whenever needed. When the mission was completed, the circuits were turned back to NASCOM to be used for some other NASA space mission, maybe at a different NASA Center.

By the end of 1964, the primitive Flight Operations Control Center used for the first Ranger missions had been superseded by the newly completed Space Flight Operations Facility (SFOF). In a dual string computer arrangement, new IBM 7094 computers performed the data processing for the Mariner 3 and 4 missions to Mars, while the Ranger processing was still carried out on a later version of the original 7040 machines. This arrangement minimized the need for changes to the existing Ranger software.

In the spacious facilities of the new SFOF building, a large high ceiling room in the middle of the first floor housed the new Mission Control Center. An attractive entrance lobby with reception desk and space-related displays occupied the front of the build-
ing, while offices and conference rooms for the various teams of flight project personnel surrounded a DSN Control Room on the other three sides. In the huge basement below the Control Room, engineers in the DSN Communications Terminal monitored, coordinated, and routed the flow of voices and data between the stations, the DSN Controllers above them, and the data processing computers on the second and third floors of the SFOF. An elaborate internal communications system enabled all the users of the SFOF to access and direct data to and from sources and destinations as their duties and authority required during the mission. The Facility was designed to run 24 hours a day, and incorporated a generator-driven “uninterruptible power supply” that would supply primary power if the commercial power failed for any reason. During critical parts of a mission, the generators would be turned on anyway to ensure that the SFOF would not suffer any kind of a “glitch” while critical mission operations were in progress. The muffled roar of the JPL generators always informed the quiet neighborhood that something important was going on at the Lab.

Over the course of thirty years, 1964 to 1994, the management responsibility for the large data processing facilities in the SFOF passed back and forth several times between the DSN and the Flight Project offices at JPL, depending on the current “financial climate” at NASA Headquarters.

However, responsibility for the two DSN control functions, Network Control and Ground Communications Control, always remained in the hands of the DSN. The consolidation of these vital functions, together with expansion of the Network itself, benefited from a continuum of long-term planning and management. As a result, the DSN was perceived from time to time to have a “monolithic structure” by other organizations within the JPL and, indeed, even by NASA Headquarters. Good relations with NASA were essential to the well-being of continued JPL involvement in the planetary space program. Nowhere was this recognized more acutely than in the Tracking and Data Acquisition Office at JPL, where the encouragement of frequent and open channels of communication between DSN personnel and NASA on DSN-related matters did much to improve working relationships and dispel the “monolithic” image of the DSN in those years. With the beginning of the S-band missions and the advent of the SFOF containing the DSN Network and Communications Control Centers, as well as the Mission Operations Control Center and its data processing facilities, the DSN began to assume the form, and much of the substance, of the modern DSN.
The Need for a Second Network

To support the more sophisticated missions of the 1965 to 1968 period, the DSN recognized the need to expand and improve its communications, mission, and network control capabilities. The two major lunar missions nearing launch readiness, Lunar Orbiter and Surveyor, would pave the way for the start of the Apollo program and would transmit data streams at thousands of data bits per second rather than the tens or hundreds of bits per second received from the Mariners and Rangers. The increased complexity of the spacecraft would require expanded and faster monitor, control, and display facilities.

For the first time, the DSN began to find that the simultaneous presence of several spacecraft on missions to different destinations created new problems in network and mission control. The vexing problem of DSN “antenna scheduling” began to arise as several spacecraft began to demand tracking coverage from the single DSN antenna available at each longitude. The difficulty of assigning priority among competing spacecraft whose view periods overlapped at a particular antenna site was to prove intractable for many years. The problem was exacerbated by competition between flight projects from NASA Centers other than JPL, each of which felt entitled to equal consideration, for the limited DSN resources. The DSN was placed in the impossible situation of arbitrating the claims for priority consideration. The regular “Network Scheduling” meetings conducted by the DSN often resulted in the establishment of priorities that were determined more by the dominant personalities in the group than by the real needs of the projects.

With all of these imminent new requirements in mind, NASA decided to embark on a program to construct a second network of DSN stations. Arguments as to where the stations were to be located were complicated not only by technical considerations, but by political and international considerations.

There were already two stations at Goldstone, one at the Pioneer site and a second at the Echo site. Eventually, NASA decided to build two new stations, one at Robledo, about 65 kilometers west of Madrid, Spain, and the other at Tidbinbilla, about 16 kilometers from Canberra, Australia.

NASA looked to the Spanish Navy’s Bureau of Yards and Docks to design and construct the Robledo station. For its new facilities in Australia, NASA dealt with the Australian Government Department of Supply through its representative, Robert A. Leslie.
As an Australian foreign national, Robert A. Leslie played a major role in shaping the relationship between NASA-JPL and the Australian government, on whose good offices NASA depended for support of its several tracking stations in that country. With family origins in the state of Victoria, Australia, and an honors degree in electrical engineering from the University of Melbourne (1947), Leslie had worked on radio controlled pilotless aircraft for the military in both England and Australia for fifteen years before he encountered NASA. He was a high-ranking officer with the Australian Public (Civil) Service (an affiliation that he retained throughout his career) when, in 1963, he became the Australian government’s representative for NASA’s new deep space tracking facility being built at Tidbinbilla, near Canberra in southeastern Australia.

As might be expected, the success of a NASA venture in a foreign country depended to a large extent on the personalities of the people who were directly involved on each side of the international interface. The foundation for the success of what later became the Canberra Deep Space Communications Complex (CDSCC) was, in no small part, due to Bob Leslie’s personal ability to “get along” with people at all levels. In representing the Australian side of negotiations between NASA and JPL, Bob Leslie was firm but gracious, capable, and friendly. His unassuming “paternal” manner endeared him alike to counterparts at NASA, his colleagues at JPL, and his staff in Australia.

Along with a few key Australian technical staff members, Leslie spent a year at Goldstone assembling and testing the electronic equipment that would subsequently be reassembled at Tidbinbilla to complete the first 26-meter tracking station (DSS 42) at the new site. He was the first director of the new Complex when it began service in the Network in 1965. It was there that he established the procedures and protocols on which all future DSN operational interactions between JPL and the Australian stations would be based.

A few years later, in 1969, Leslie left the “hands-on” environment of the deep space tracking station to head the Australian Space Office, a branch of the Australian Government that, under various names and government administrations, would guide future expansion and consolidation of all NASA facilities in Australia. In that capacity, his charm, experience, and wisdom served the DSN well.

Leslie’s build was stocky and solid, his appearance craggy, his attitude “laid back.” Cheerful, sociable, easy to talk to, and blessed with a good sense of humor, he was held in high regard by everyone he met, Australian or American. Tennis was his sport,
fishing his hobby, and “do-it-yourself” home building his passion. In his younger days, he actually excavated the ground with shovel and wheelbarrow and single-handedly built the family swimming pool at his home in Canberra. Many a JPL engineer enjoyed a poolside barbecue at the Leslie home in the course of a technical visit to the station.

Robert Leslie retired in 1983 and died in Canberra, Australia, in 1996.

By mid-1965, the two new stations were completed and declared operational. The DSN then had two stations in Australia, (Woomera and Tidbinbilla), one in Spain, and one in South Africa. In addition, a permanent spacecraft monitoring station had been built at Cape Canaveral to replace the temporary facility with its hand-steered tracking antenna. Impressive as this growth was, still greater changes were in progress.

**Larger Antennas Are Needed**

Consistent with the JPL vision for missions to more distant planets, and more powerful communications links to support them, the DSN had long recognized a need for larger antennas, that is, larger than the existing 26-m antennas. Studies had shown that a diameter of 64 meters was about the maximum practical limit to an antenna which would have sufficient stability and structural integrity for DSN purposes. Interest in building a giant new antenna of that size, employing radical new design and construction techniques, became a reality as early as 1962 at NASA and JPL. Feasibility study contracts for an advanced antenna had already been issued to numerous U.S. corporations and, finally in January 1963, the Rohr Corporation was selected to build the antenna at a suitable site a few miles from the existing Echo and Pioneer locations at Goldstone. Since the advanced antenna was originally intended to support the first missions to Mars, the site was appropriately called “the Mars site.”

Design work began immediately (1963), and procurement and fabrication of steel components started a year later. Roads, concrete foundations, alidade structure, and diesel generator buildings were completed in 1964, followed by the control room and elevation bearings. The supporting framework for the antenna panels followed next, and by mid-1966, the 64-meter Mars Antenna was ready for service. Although the first signals from Mars—transmitted by *Mariner 4*—were detected in March 1966, a great deal of performance testing, personnel training, and calibration remained to be completed before the Mars antenna was considered a fully operational addition to the DSN.

Figure 2-5. Side elevation of the 64-meter azimuth-elevation antenna at Goldstone, 1966.
Designed to remain operating in wind speeds as high as 80 km per hour, the Mars antenna was constructed of massive steel beams, which, together with its pedestal, weighed about 33 million kilograms. At wind speeds exceeding 80 km per hour, the antenna was stowed in a fixed position to protect it from permanent damage. In that position it

Figure 2-6. The 64-meter antenna at Goldstone, 1966. The pickup truck parked to the right side of the pedestal gives an impression of the immense size of the antenna.

Designed to remain operating in wind speeds as high as 80 km per hour, the Mars antenna was constructed of massive steel beams, which, together with its pedestal, weighed about 33 million kilograms. At wind speeds exceeding 80 km per hour, the antenna was stowed in a fixed position to protect it from permanent damage. In that position it
could withstand hurricane force winds. The dish, and its azimuth-elevation mounting atop the pedestal, weighed nearly 13 million kg. The structure rotated in azimuth on three flat bearing surfaces that floated on a pressurized film of oil, about the thickness of a sheet of paper. The reflecting area of the dish surface was 3,850 square meters. It could be pointed to a given position in space with an accuracy of 0.006 degree. The major structural components and dimensions of the 64-m antenna are evident in the side elevation shown in Figure 2-5.

In a single, major step forward, the Mars antenna provided the DSN with more than six times the transmitting power and receiving sensitivity of the 26-meter antennas, and more than doubled their tracking range. This was a significant new capability indeed. But, important as it was, it was only one in a series of stepwise improvements that took place in the DSN in the mid-1960s. A photograph of the new 64-meter antenna at Goldstone, taken soon after its completion in mid-1966, is shown in Figure 2-6.

Most of the credit for the conceptual design of the Goldstone 64-m antenna, the first of its kind ever built for tracking planetary spacecraft, went to a brilliant electrical engineer who had come to JPL originally in 1951 to work on missile tracking systems during the Corporal and Sergeant tests at White Sands. His name was William D. Merrick. In 1958, it was Bill Merrick who masterminded the design and construction of the first two 26-m antennas at Goldstone before taking up the job of project manager for the Advanced Antenna System. The “Hard Core” Design Team that Merrick formed to carry out the complex design and analysis task for the new 64-m antenna contained the best engineering talent in the fields of servos, microwaves, mechanical, optical, structural, civil, electrical, and hydraulic engineering, stress analysis and contract management that could be found at JPL or elsewhere.

He managed his “Hard Core” team, and the contractors who eventually built the antenna, in a somewhat unorthodox manner, but the on-time, in-budget and to-specification end result demonstrated the efficacy of his management style.

Although he insisted on high standards of performance from his people, his propensity for practical jokes and his sense of humor endeared him to those who worked on his team. Those who needed to direct or limit his activities found him difficult. He thought of himself as a person who got things done regardless of obstacles such as budget constraints, administrative orders, or alternative opinions that stood in his path. He could always find a way around them.
When the Goldstone 64-m antenna was completed in 1966, it was regarded by many who appreciated the effort that he put into it as a testament to Bill Merrick. After the 64-m antennas in Spain and Australia were completed, Merrick moved from the “hands-on” engineering, at which he excelled, to a staff position which offered little challenge for his special talents.

Bill Merrick retired from JPL in 1984 to take up a position in industry, and died at his home in Ventura, California, in 1997.

**Incremental Improvements in the Network**

Important as it was, the new 64-m antenna at Goldstone was only one of many improvements in technology and management that were added to the Network in the mid-1960s. Like the 64-m antenna, each change represented an incremental increase in the overall capability and performance of the Network. As Corliss put it, “The DSN did not suddenly change from a lunar to a planetary network, or a low-bit-rate network to a high-bit-rate network, or a network burdened with mission-dependent equipment to a multi-mission network. The DSN was always being upgraded, some of the steps were small, some of the others were big.” Although there were many changes in many areas, some small, some large, among the most important at this time was the improvement in the DSN ranging system.

The technique of measuring the range (distance) from a reference point on Earth, to a spacecraft at lunar distance, to an accuracy of a few centimeters was one thing. To do the same thing for a spacecraft at planetary distance required a significant new technique for measurement of range. A Lunar Ranging system, known as the Mark I, was already in place in the mid-1960s. Although it was designed for the lunar missions, it had successfully tracked *Mariner 5* out to nearly ten times the distance of the Moon.

Planetary ranging, however, would require a hundredfold increase in capability. This could be achieved with new and more complex range codes transmitted to the spacecraft on the uplink, and new methods of detecting and decoding the range code retransmitted from the spacecraft on the downlink. More precise methods for calibrating the system, and for measuring time, would also be required. Two planetary ranging systems were developed in this period, one by Robert C. Tausworthe, the other by Warren L. Martin. The two systems were aptly named the “Tau” and the “Mu.” In Tausworthe’s design, the time delay between a pseudo-random code transmitted on the uplink and returned on the downlink was used to measure the range of the spacecraft. Martin’s design used a sequential binary code, assisted by a Doppler rate-aided function to carry out the decoding, for range meas-
measurement. This design also automatically produced a type of data called DRVID, for Differenced Range versus Integrated Doppler, which allowed the range data to be corrected for the effects of charged particles along the path between spacecraft and tracking station. Together these improvements extended the performance of the Mu system to the point where high-precision ranging measurements were possible out to a range of 2.6 AU.

The Mark I, and a later Mark IA version, was used for the Lunar Orbiter and Surveyor missions in 1966 and 1967. The Tau planetary ranging system saw its first operational use on Mariner 5 in 1967 and 1968, and an improved and more stable version of the Tau system was used from 1969 to 1971 for Mariners 6 and 7. Later still, the Mu ranging system appeared in the Network and was used for relativity experiments on the extended missions of Mariners 6 and 7 in 1970.

For the accurate ranging required by the Lunar Orbiter mission, the electronic clocks at the various tracking stations had to be synchronized to within 50 microseconds of the master clock at Goldstone. In the early days, the DSIF had to rely on radio signals from WWV for station time-keeping purposes. The most accurate measurement at the time was in milliseconds rather than microseconds. Later, transportable cesium atomic clocks from the National Bureau of Standards offered improved accuracy for station time synchronization. However, this method proved to be too expensive and inconvenient for operational use. A more operationally convenient method of time synchronization using the spacecraft itself was eventually implemented for Lunar Orbiter and improved the accuracy to 20 microseconds.

As usual though, the DSN was looking for something better. It showed up in 1966 as the “Moon-bounce Time Sync” scheme. This depended upon the propagation delay of a precision timed X-band signal which was transmitted from the Goldstone Venus station to each of the overseas stations during their mutual lunar-view periods. The Goldstone Venus station acted as master timekeeper and timing signals reached the desired stations via the Moon. By 1968, the DSN was setting its clocks to an accuracy of 5 microseconds using this technique, which had been adopted for operational use throughout the Network.

Driven by the rapidly increasing data rates being transmitted by the new spacecraft coming into the DSN, the capability of the ground communications system had to be expanded to permit the tracking stations to return data to JPL as rapidly as possible. More stations needed more operational voice and teletype traffic to control them. Consequently, in 1967, a new computer-based teletype communications switcher was
installed in the Com Center in the SFOF and the high-speed data circuits were upgraded to carry 2,400 bits per second.

The SFOF, too, felt the pressure to keep up with the ever-increasing requirements for higher data rates on the uplinks and downlinks for the new missions. The SFOF data processing capability was expanded to three computer strings, each comprising an IBM 7044 and large disk memory for input/output processor functions, followed by an IBM 7094. The 7094 was used as the primary processor for the complex calculations related to orbit determination; it generated antenna pointing and receiver tuning predictions used for initial acquisition, calculated the parameters needed for spacecraft maneuvers, and manipulated the spacecraft tracking data generated by the DSN stations. In addition, a special system was developed to display monitor and performance data for the DSN station controllers.

**Flight Project Requirements Become Formalized**

By 1967, the interactions between the DSN and new flight projects needing DSN support had become very formalized. No longer were all the missions managed by JPL, where loose interdepartmental agreements would suffice to commit funds and resources to meet a specific JPL objective. Now, other NASA Centers were responsible for the spacecraft and its scientific payload, and the function of JPL was to provide the tracking and data acquisition support using the resources of the DSN. Even within the JPL institution, the changing management organization at NASA Headquarters was reflected in entirely separate funding channels for the flight project and the DSN organizations. This situation resulted in a very formal process for the presentation of flight project requirements to the DSN, and the acceptance (or rejection) of these requirements by the DSN.

NASA Headquarters insisted that these negotiations be set out in detail in two formal documents, the Support Instrumentation Requirements Document (SIRD) for the flight projects, and the NASA Support Plan (NSP) for the DSN. Before any flight project could begin to effectively design its mission, it not only had to have a signed SIRD from one office of NASA Headquarters but a signed NSP from another. With these in hand, a newly approved flight project could truly begin. In the years ahead, the relationship between the DSN and all flight projects would always be a reflection, for better or for worse, of the SIRD/NSP negotiations.

Finally, the DSN was beginning to use computer assistance to resolve mounting conflicts for station time, not only for spacecraft tracking purposes but also for station maintenance, implementation of new hardware and software, and testing time. Also, the stations were becoming much more complex, and consequently required more time for calibration, con-
configuration and check-out prior to the start of each tracking pass. In addition, the flight projects were becoming less tolerant of station outages which depleted their hard won tracking time allocation. The persistent issue of tracking time allocations would never go away; it was ameliorated somewhat as techniques to manage it improved, but it never went away.

This was the state of the DSN when, within a very short period it found itself dealing with more spacecraft than any of its people could have imagined a few short years earlier.

**The DSN Becomes a Multimission Network**

Referring to this period in the history of the DSN, William Corliss wrote, “The NASA lunar exploration program absorbed the bulk of the DSN support capability during the 1966-1968 period. Surveyor, Lunar Orbiter, and the backup support provided to the first Apollo flights combined to utilize the DSN almost fully. The lunar program at this time consisted of short-lived missions, a few days long, and the DSN was able to divert some of the support necessary for the Mariner 5 shot to Venus and also accord some support for Pioneers 6–9, which kept on operating long after the ends of their nominal missions. Mariner 4 was also picked up again and became another example of an extended mission. The new 64-meter Mars antenna was called upon to support almost all of these missions, although not always as a prime station. The DSN during this period was not yet a multimission network, although it was supporting many missions simultaneously. The DSN stations were still crowded with mission-dependent equipment and this situation was the very antithesis of a multimission philosophy.”

These and other issues related to the general problem of data return from deep space are discussed by Hall, Linnes, Mudgway, Siegmeth, and Thatcher and an excellent description of the growth of the DSN from inception through 1969 is given by Renzetti et al.

To simplify the increasing problem and cost of accommodating the many different kinds of special telemetry and command processing equipment appearing at the tracking stations to support the various missions, the DSN developed a “multi-mission” philosophy.

Instead of each flight project bringing its own equipment (and people to operate it) to the stations, the DSN would provide a generic set of equipment capable of operating over a wide range of parameters at each station. Future projects would have to design their uplinks and downlinks to fall within the capability of the equipment provided by the DSN. That way, all flight projects could use the same set of ground support equip-
ment, and operations costs and complexity could be reduced. With some modification, this concept has been preserved to the present time.

Its success has been largely due to the DSN policy of advanced development, in keeping the DSN capability well ahead of the flight projects’ demands to use it. The DSN was able to do this by basing its long term planning on judicious forecasting of future mission requirements.

By the early part of 1968, the Lunar Orbiter and Surveyor Lander missions had been concluded. Spectacularly successful, they had returned an avalanche of lunar surface and other science data, which was assimilated into the design studies for the Apollo piloted missions.

It was not realized at the time that a DSN mission would not view the Moon again for nearly twenty-five years. In December 1992, a remarkable picture of the Moon in orbit around Earth would be captured by a spacecraft called Galileo, outbound on a mission to Jupiter and its satellites. By then, the DSN and the environment in which it functioned would be very different indeed.

The missions to follow over the next six years (1968–1974) would focus the DSN’s attention outward to even more distant planets and to the Sun. During these years, the DSN made enormous improvements in its operational capability to meet the requirements of the new planetary missions.

New telemetry and command systems with true multimission features were added throughout the Network. Not only were these additions multimission in nature but their ability to run at higher data rates on the uplink and downlink had been increased to 16 kilobits per second for telemetry and 32 bits per second for the command link. New forms of coding the downlink data to improve the quality of the science data delivered to the flight project had also been developed.

The speed of identification and correction of problems in the Network was improved by giving station controllers better tools to monitor and control the configuration, status, and performance of remote tracking stations.

The Doppler and ranging data generated by the tracking stations and used by the flight projects for spacecraft navigation purposes was improved in accuracy and extended in range. Studies were made to better understand the disturbing effect of charged particles on the radio path between the spacecraft and the DSN antennas. Thrown off by the Sun, these
particles introduce delays in the radio path and consequent inaccuracies in the navigation data. Ways of calibrating out these undesirable effects were found and put into effect.

To create a realistic operational environment to train DSN operators prior to the start of a real mission, the DSN uses a Simulation System. Electrically generated signals can be programmed to simulate a real spacecraft under a variety of flight conditions. Artificial faults can be introduced and the operations personnel can be trained in the proper reactions. With an increasing number of more complex spacecraft coming into the Network in the early 1970s, a Simulation Center was established at JPL to carry out the simulation tasks for all missions. Conversion assemblies at the stations allowed the individual stations to interact with the “SIM Center” to suit their individual training needs.

The addition of “wideband” circuits that could handle data at 50 kilobits per second between the Goldstone Mars station and the SFOF, and 28.5 kilobits per second to Spain and Australia, gave the Ground Communications Facility (GCF) as it was now called, a capability to deliver the increased volume of data from the now enhanced DSN to the SFOF. Because the existing high speed circuits, operating at 4800 bits per second, could handle much of the traffic formerly handled by teletype, the teletype services were phased out.

It had become obvious that the SFOF itself would not be able to cope with the demands of the future flight projects for data processing and handling. The data streams planned for the future Mariner and Viking missions to Mars would overwhelm the data-handling capability of the old IBM 7040/7044 generation of computers. An Advanced Data System study group recommended a completely new design for the new Mark III SFOF, which involved, among other things, replacing the old machines with new IBM 360/75s.

No longer an appendage to the DSN, the SFOF became an autonomous organization with full responsibility for supporting the flight missions. DSN responsibility in the SFOF was redefined to cover only Network control and the data processing necessary to carry out that function.

Openings and Closings

The tremendous improvement (a factor of six times over a 26-meter station) in uplink and downlink performance, afforded by the 64-meter antenna at Goldstone, was offset somewhat by the limitation of a single antenna at only one longitude. To provide the continuous coverage with high performance required by the new missions, similar antennas in Spain and Australia would be needed. The viability of the 64-meter design had already been established by the Mars station experience, and by June 1969, the Collins
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<td>1973</td>
</tr>
</tbody>
</table>

* A maintenance facility. Besides the 26-m (85-ft) diam Az-El mounted antenna, DSS 13 has a 9-m (30-ft) diam Az-El mounted antenna that is used for intersatellite time correlation using lunar reflection techniques, for testing the design of new equipment, and for support of ground-based radio science.

Figure 2-7. Composition of the Deep Space Network, 1974.
Radio Company of Richardson, Texas, had been selected to build two more 64-meter antennas. To simplify logistics and support facilities, the new antennas would be built near the existing 26-meter sites at Canberra, Australia, and Madrid, Spain.

Construction of the Australian antenna began soon after and was completed in three years, without significant delays, in mid-1972. Electronics were installed and tested and, after a period of calibration, operator training, and performance demonstration tracking, the station reached full operational status in April 1973.

Although work on the Spanish antenna encountered some problems along the way, it followed a similar pattern and was declared operational in September 1973. By this time, a second 26-meter antenna had been added to each of the complexes at Madrid and Canberra.

The DSN now had two networks of 26-meter antennas plus a complete network of 64-meter antennas. They would be numbered so as to indicate the areas in which the antennas were located; 11 to 19 for Goldstone, 41 to 49 for Australia and 61 to 69 for Spain. Thus the DSN would consist of Deep Space Station 14 (DSS 14) at Goldstone, DSS 63 at Madrid, and DSS 43 at Canberra, plus the six 26-meter stations, which were similarly identified.

At each location, the number and types of antennas continued to increase. Larger buildings were built to house the hundreds of racks of electronic equipment required to control the antennas, and to transmit, receive, record, and process the spacecraft data before it could be fed to the NASCOM communication circuits for transmission back to JPL. Instead of a single antenna and a modest Control Room at each longitude, there were now several antennas, a Signal Processing Center, power station, cafeteria, laboratory, workshops, offices, and supporting facilities. The entire establishment had become a Deep Space Communications Complex (DSCC)—GDSCC for Goldstone, CDSCC for Canberra, and MDSCC for Madrid.

The new complexes at Canberra and Madrid now provided the support formerly given by Woomera and Johannesburg, both closed by NASA: Woomera for economic reasons, Johannesburg for diplomatic reasons. The composition of the Network as it existed in 1974 after these closings had taken place is tabulated in Figure 2-7.
LOOKING BACK

Born out of the challenge to the prestige of American technology created by the appearance of the Soviet satellite Sputnik in October of 1957, by 1974 the DSN had evolved into the world’s largest and most sensitive radio communications and navigation network for unpiloted interplanetary spacecraft engaged in the exploration of the solar system.

From a loose collection of remote transmitting and receiving stations maintained and operated by essentially dedicated engineering personnel from JPL, the DSN had matured into a fully integrated global network of operational tracking stations, maintained and operated by competent nationals of the cooperating countries in which the sites were located.

It had become a worldwide organization of tracking stations, located on three continents and connected by high quality communications satellite and cable links to a Control Center in Pasadena, California. From there, a web of phone, teletype, and modem circuits distributed scientific data in various forms to the science community in research centers and universities throughout the U.S. and to several experimenters at locations in other countries.

Fifteen or so years after inception, the Pioneer, Ranger, Surveyor, Lunar Orbiter, and Mariner spacecraft had carried out scientific missions to the Moon, Sun, Mercury, Venus, Mars, and Jupiter with great success. These spacecraft were spread out in all directions and distances throughout the solar system. During these years, the DSN was frequently called upon to track as many as six such spacecraft simultaneously, the limit to the requirements being set by the number of antennas in the DSN itself.

Two big Voyager spacecraft were being built for 1977 missions to Jupiter. Two ambitious Viking missions to Mars, even though they would not be launched for another year, were demanding and getting most of the DSN attention.

Yet, this was the era of the Mariners. As it drew to a close, the DSN was moving toward a new phase of development. It would be simultaneously involved with several large flight projects directed not by JPL, as had been the case in the Mariner program, but by other NASA Centers or by foreign space agencies. We will refer to this period of the DSN history as the Viking Era.
Endnotes


