Mariner 10 Mission Support

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This is the last in a series of DSN mission support articles on the Mariner Venus/Mercury 1973–Mariner 10 Project. This report covers the period from February 15 through April 15, 1975. The primary objective during this time was, of course, a successful third encounter of the planet Mercury on March 16, 1975. Other special support activities included trajectory correction maneuver number 8 conducted on March 7, 1975, and restabilization of the spacecraft via acquisition of the reference star Canopus. This period also saw the DSN involved in (1) assisting the Project in obtaining adequate tracking coverage, (2) monitoring DSN implementation for Viking to assure maintenance of capabilities required for Mariner 10, and (3) conducting pre-encounter data flow tests to verify Network support readiness. As planned, the extended mission was terminated during this period, marking the end of the highly successful Mariner Venus/Mercury 1973–Mariner 10 Project.

I. Trajectory Correction Maneuver Number 8

As reported in the previous article, trajectory correction maneuver number 7, conducted on February 13, 1975, was not of the required accuracy. The DSN interface organization assisted the Project in negotiating additional Deep Space Station (DSS) tracking time in order to rapidly and accurately determine the post-burn orbit. Readers are reminded that Mariner 10, at this time, had the lowest priority among the projects supported by the DSN (Pioneers 10 and 11, Helios A, and Viking). However, a minimum but adequate number of additional tracking passes were made available. By late February 1975, orbit solutions indicated that about 50% of the 3-sigma target error ellipse was within the planetary impact–capture zone. An eighth trajectory correction maneuver was, therefore, required to give the spacecraft the required 90% probability of no impact.

Trajectory correction maneuver number 8 was planned and supported on March 7, 1975. The maneuver was of a sun-line type with the spacecraft placed in the all-axis-inertial mode during the engine burn. Following the burn, the spacecraft was, however, returned to the roll-drift, solar-sailing mode to assure preservation of attitude control gas for Mercury encounter operations. A slow, 24-hour-period roll rate was planned to help accommodate later acquisiton of Canopus and to provide suitable telecommunications link conditions for loading the encounter sequence in the spacecraft computer. In keeping with coverage conflict resolution agreements described in the previous article, trajectory correction maneuver number 8 was timed to be supported by DSS 63. This minimized impacts on other flight project support, particularly Helios A, which obtained zero-longitude support from the German tracking station. Deep Space Network support of the maneuver, as well as special post-burn radio metric data generation activities, was very satisfactory, leading to rapid verification that the required aim point had been achieved.

II. Canopus Acquisition

Canopus acquisition, the next critical event prior to encounter, proved to be a delicate and difficult operation. Uncertainty in the spacecraft roll rate and less than continuous 64-meter subnet coverage contributed to the acquisition problem. Again, for coverage conflict resolution purposes, it was planned that Canopus acquisition would be conducted during the DSS 63 view period. Assuming accurate knowledge of the spacecraft roll rate, the planned procedure was to send a command sequence which would turn on the roll axis attitude control when Canopus entered the tracker's field of view. With the slow spacecraft roll rate, Canopus would then still be acquired following the 18-minute round trip light time. The spacecraft would then be placed in the roll-axis-inertial control mode to preclude the possibility of a bright particle incident causing loss of roll reference prior to or during encounter. Consequently, the acquisition could be accomplished without risking the possibility of attitude control gas depletion due to oscillations induced by a roll search.

Obviously, accurate knowledge of the spacecraft's roll position and roll rate was essential to achieving Canopus acquisition using the described procedure. The reader is reminded that communications with the spacecraft while in the roll-drift mode was via the spacecraft's low-gain, omnidirectional antenna. The resulting antenna pattern provided only a few peaks and deep nulls in a relatively flat signal level for determining spacecraft roll. However, through comparison of 64-meter deep space station received signal level with the known antenna pattern, the Project expected to be able to clock the spacecraft roll with sufficient precision to initiate the acquisition sequence.

Scheduled DSS 63 passes on March 10, 11, and 12, 1975, were devoted to spacecraft roll timing, and the Project's calculations indicated that the best time for an acquisition attempt fell at a time when no 64-meter DSS coverage could be made available. Therefore, Project took action to slow the spacecraft roll such that the Canopus crossing would be delayed to occur over DSS 43, where partial-pass coverage could be scheduled. However, the ensuing acquisition attempt on March 12, 1975, was not successful.

The next acquisition attempt on March 13, 1975, was also unsuccessful since the spacecraft roll rate was apparently higher than expected, resulting in the spacecraft being stopped about 7 degrees beyond Canopus. Project then executed a series of spacecraft roll direction changes in an attempt to find Canopus but without success. Concern grew and a spacecraft emergency was declared. The DSN negotiated with the Helios Project JPL representative for release of DSSs 14 and 43 from Helios A to support two Mariner passes. Although Helios agreed in this one case, there was strong opposition to any further reduction in 64-meter subnet coverage; to do so would seriously impact Helios prime mission objectives at perihelion on March 15, 1975. At one point, in the absence of 64-meter DSS support, DSS 12 employed an experimental tracking loop of 3-Hz bandwidth in the Block III receiver to improve signal detection capabilities. This effort was successful in providing the Project with critical signal level information which indicated that the spacecraft was, in fact, rolling toward a position of improved signal rather than toward a deep null. It was rapidly becoming clear that the low-gain antenna mapping technique was not an adequate tool for Canopus acquisition.

It was decided that the spacecraft high-gain antenna, with its narrow beam and precisely calibrated pattern, offered the best means of determining the spacecraft's position and, consequently, Canopus acquisition. This required stopping the spacecraft roll and pointing the high-gain antenna at Earth. The plan was put into effect, and DSS 42 was employed to first get a precise calibration on the roll position. Then, using the received signal level and the pattern to confirm roll position, the spacecraft was allowed to roll-drift toward Canopus. This process took place in carefully controlled steps to assure success. The spacecraft was stopped 40 degrees short of Canopus and again at 7 degrees short to confirm the roll position. At this point, signal level readouts from DSS 63 were provided every 5 seconds as the spacecraft rolled the last 7 degrees. The reported signal levels tracked very precisely along the predicted plot. At the proper time, allowing for one-way communications, the roll-drift stop commands were sent to be received at the spacecraft while Canopus was still acquired by the spacecraft tracker. The technique worked and Canopus was acquired.

The spacecraft was stabilized to celestial reference, and the encounter sequence was initiated shortly thereafter.

III. DSN Encounter Readiness Tests

As described in the previous article, a brief but adequate test plan was designed to revalidate DSN 64-meter subnet encounter support configurations and data flow capabilities. As planned, this test plan was executed in early March 1975 but not without some difficulties. Very limited DSS time was available for tests due to the higher priority activities of other projects as well as Mariner 10's critical events described above. By March 6, 1975, the situation had become critical, and special steps were taken to gain additional test time for a concentrated effort on March 7 and 8, 1975. Stations were instructed to give priority to completion of internal system performance tests. Negotiations with the Viking Project resulted in cancellation of one Viking systems integration test in order to provide DSS 14 test time for Mariner 10.

All test objectives were met by March 10, 1975, and the DSN held a brief encounter readiness review on March 13, 1975. Although the review verified that DSN preparations for encounter were adequate and complete, concern continued to be expressed regarding the limited number of test and training exercises and regarding use of the newly implemented Block IV receiver–exciter configuration at DSS 14.

In addition, it was also planned that end-to-end data flow tests would be conducted with the spacecraft following Canopus acquisition on March 12, 1975. The availability of actual spacecraft data rather than simulated data would have provided a precise demonstration. Unfortunately, these tests were cancelled due to Canopus acquisition difficulties. Consequently, the DSN-supported third encounter had the benefit of only one successful test with each supporting 64-meter station.

IV. Mercury Third Encounter

The encounter sequence was initiated on March 15, 1975, with turn-on of the TV cameras at about 1000 GMT over DSS 63. An incoming TV mosaic was performed as planned; however, the planned color mosaic was delayed 2 hours due to a spacecraft inertial reference update being required. Ground commanding was required to accomplish the color TV mosaic over DSS 14. Problems at the DSS 14 Block IV exciter–transmitter interface caused command aborts during the second command of this sequence. Action was taken to re-establish DSS 14 command capability via the Block III exciter. Although this was subsequently accomplished, the color mosaic sequence was too far behind the time line and had to be aborted.

Before further discussing DSN support for encounter and another problem associated with that support, it is important to first understand the objectives and situation. The primary objective of third Mercury encounter was the investigation of Mercury's magnetic field and particles. The aim point was optimized to provide acquisition and return of these non-imaging data. Also, as reported in the previous article, third encounter offered excellent geometry for the celestial mechanics experiment through the continuous acquisition of two-way doppler data and ranging points. As a secondary objective, TV data were to be acquired at the full resolution, 117-kbps rate. The non-imaging 2450-bps science was the prime data type having priority over data for accomplishment of other objectives. Consequently, the DSN configuration was such to assure the acquisition, recording, and real-time handling of 2450-bps data rather than video data as on previous encounters. This meant that redundant DSN equipment and data paths were assigned to the non-imaging science rather than to video. Attention was, however, also given to the generation of radio metric data for celestial mechanics purposes and to the acquisition of TV data, but not at the expense of the prime data type.

As with previous Mercury encounters, acquisition of full resolution video data at 117 kbps depended upon proper operation of an experimental, R&D super-cooled maser-ultra cone at DSS 43. This R&D ultra cone was installed at DSS 43 prior to Mercury first encounter to provide for mission enhancement well beyond that which could be gained via the standard 22-kbps mission. Successful use of the ultra cone on the first two Mercury encounters resulted in TV science returns well beyond expectations. R&D devices are only occasionally used in the DSN for operational support with the understanding that they are for mission enhancement purposes, for experimental tests in parallel with operations, and are provided on a best-efforts basis with spares, documentation, testing, and training much less than that normally associated with operational commitments. Use of such equipment carries a higher risk of failure which must be weighed against the potential increase in returns. On Mariner Venus/Mercury 1973, the returns were well worth the gamble. The foregoing is offered to point out that failures in R&D equipment should not be unexpected and that such failures should not be considered as having a serious effect on primary objectives. Some other post-encounter reports offered comments to the contrary.

As the reader might suspect, the DSN had problems with the R&D ultra cone super-cooled maser at DSS 43 during third encounter. On March 14, 1975, word was received that the maser was not cooling down as expected. DSN maser cognizant design engineers were assigned to work with DSS 43 via voice circuit in an all-out effort to effect repairs. The maser was removed, equipped with new cross head and cleaned. JPL engineers continued coordination with DSS 43 throughout March 14–16, 1975, and provided special recommendations regarding cool-down procedures. This effort was not successful and the maser remained warm.

The failure was reported to the Project and frequent progress reports were provided in order that the Project could be ready to make a decision as encounter approached. Even with the standard cone and maser at DSS 43, two options were still open: (1) acquire 117-kbps video containing a high bit error rate (6–10 bits in error per 100) while gaining area coverage or (2) change the data rate to 22 kbps to acquire very high quality but quarter-frame pictures. The Project opted in favor of quality rather than quantity and chose the 22-kbps rate.

The DSN provided continuous, high-quality acquisition and real-time handling of the 2450-bps non-imaging data throughout the third encounter. Also, continuous two-way S-band doppler data were generated, and periodic ranging points were acquired as required for celestial mechanics. DSS 43 performed in an excellent manner for acquisition and transmission of all 22-kbps video data in real time to JPL. Therefore, overall DSN support for this encounter was very satisfactory.

Following encounter, the DSN supported a number of science calibration and spacecraft engineering tests through March 24, 1975. On March 24, data received reflected that the spacecraft had depleted its attitude gas supply. Shortly thereafter, at 1200 GMT, the command was sent to turn off the spacecraft transmitter. DSS 63 observed loss of signal one round-trip light time later indicating that the mission indeed had ended.

Table 1 summarizes some of the significant Project and DSN accomplishments and firsts which were associated with the very productive Mariner Venus/Mercury 1973 mission.

Table 1. Significant Project/DSN mission achievements

First multi-planet gravity assist mission
First spacecraft to photograph Venus
First spacecraft to approach and photograph Mercury
First spacecraft to have multiple encounters with target planet
First spacecraft to effectively conserve attitude control gas by the "solar sailing" technique
First spacecraft to successfully complete eight trajectory correction maneuvers
First JPL spacecraft to transmit full resolution pictures in real time from planetary distances
First mission to use dual-frequency radio transmission
First mission to use arrayed ground station antennas to improve signal-to-noise ratio