Pioneers 10 and G Mission Support

A. J. Siegmeth
Mission Support Office

The DSN has already completed 6 months of continuous telemetry data acquisition, command, and radio metric tracking support for Pioneer 10, which was launched on March 4, 1972. The Pioneer 10 spacecraft, on the way to the giant planet Jupiter, crossed the orbit of Mars during the first part of May and entered the asteroid belt in the middle of July 1972. A summary of extended mission support capabilities is presented.

The 250-kg Pioneer 10 spacecraft is the first man-made object to enter into the 210-million-km-wide asteroid belt region, where huge chunks of solid debris hurtle through space at tremendous speed orbiting the sun. Astronomers estimate that at least 50,000 of these asteroids measure 1.5 km or more in diameter. Ceres, the largest, is 900 km across. There is no way of knowing how many millions of small asteroids are circling the sun ranging in size from 1 km down to pebbles, sand, and meteorites. Even a relatively small asteroid could damage Pioneer 10 seriously. Such a disaster could become known on Earth only after the spacecraft downlink signals were lost.

The distribution of large asteroids in the asteroid belt is sparse enough to allow safe passage; it is the concentrations and sizes of asteroid fragments and dust particles traveling approximately 15 km/s relative to the spacecraft which cause concern. (A bullet leaving the muzzle of a military rifle travels approximately 1 km/s.)

Since the asteroids are scattered far apart in the vastness of space, it is still a high probability that Pioneer 10 will conquer the hostile environment of the solar system and leave the asteroid belt safely in January 1973 to continue the voyage towards its next objective, Jupiter. Pioneer 10 will arrive at the largest planet of the solar system on December 4, 1973. The DSN has continuously collected the Pioneer 10 downlink telemetry signal, using almost all 26-m antenna stations of the network. Every operational measure was and is taken to monitor continuously the performance of the telecommunications downlink to assure the detection of any deviations from nominal values affecting this link by any unforeseen collision processes. The DSN has also provided one tracking pass per week from the 64-m-antenna station at Goldstone to enhance telemetry performance and obtain precision two-way doppler-type radio metric information.

The telecommunications downlink operated during high elevation angles of the station antennas at 1024 bps. During the entrance and exit phases of the tracking passes the Project commanded the spacecraft telemetry rate to 512 bps to assure an errorless downlink telemetry stream obtained at the output of the sequential decoder from the on-site equipment. During the DSS 14 passes at Goldstone, the Project operated Pioneer 10 at a telemetry bit rate of 2048 bps.

To probe the hazards of space flight, Pioneer 10 is carrying a meteoroid detector. Dr. W. H. Kenard and four co-investigators at the Langley Research Center are concerned with encounters between the spacecraft and very small bits of matter. This experiment has panels of pressurized cells mounted from the back surface of the Pioneer 10 high-gain antenna, and penetrations of the cells are counted. The rate at which pressure is lost from a cell indicates the size of the hole made; and thus the mass and incident energy of the particle responsible will be learned. By combining such findings with trajectory data, the researchers will establish the statistical distribution modes of the spacial density of small meteoroids having masses of 10^{-9} g or more.

By August 9, the Pioneer 10 meteoroid detector registered a total of 63 hits. The first penetration was observed one day after Pioneer 10 launch, and one to seven hits were experienced during each 10 days of flight. As the spacecraft crossed the Mars orbit trace, no hits were observed for approximately eight days.

Telemetry information obtained from the asteroid meteoroid detector (also called Sisyphus) is under study. This instrument can detect particles ranging upward in mass from 10^{-6} g, and it can detect asteroids and meteoroids by the solar light that they reflect and scatter. Four independent telescopic subsystems provide four overlapping fields of view, and the light signatures are detected by photomultiplier tubes. The ranges and velocities of optically observed particles can be found by timing the entries and departures of the reflections in those four fields of view. The principal investigator of this detector is Dr. R. K. Soberman. Besides data obtained from the described asteroid and meteoroid detectors, the continuous collection of Pioneer 10 telemetry data by the DSN also provided to the other nine experimenters new information on the environment of the solar system never before probed by any spacecraft.

Preceding the official change of the Pioneer Project/DSN interface in July 1972, the DSN delivered the 360/75 Model 6 software in June. This software included an automatic command transmission capability from the Remote Information Center of the Pioneer Project located at Ames Research Center (ARC), Moffett Field, California. Using this command input terminal, the Project started to send most of the automatic commands from ARC to the Pioneer 10 spacecraft via the Central Processing System located at the Mission Control and Computing Center (MCCC) at JPL to the Deep Space Stations. DSN has also delivered in June a capability to merge data records from the DSN-generated System Data Records and Original Data Record playback tapes. This merged Master Data Record capability is compatible with the Pioneer off-line system generating Experimenter Data Records.

Besides an automatic commanding capability provided to the flight project, the DSN has also tested emergency command transmission equipment and trained personnel. If for any reason the high speed data lines for interconnecting computers should fail, making the immediate transmission of commands to the spacecraft from the Pioneer Mission Control Area not possible, the DSN provides this emergency command capability. In this configuration the Mission Controller provides verbal instructions via voice line to the network Operation Control Chief and Station Controller. This voice command is entered at the stations by the telemetry and command processor (TCP) operator in the on-site computer via a keyboard device. Fail-safe voice command monitoring and verification techniques are also used to assure the timely transmission of commands necessary during possible urgent corrective actions. The DSN has also shortened the switchover time of telemetry bit rate and format changes at the stations to 1 min. This procedure makes possible speedy changes in the operational configuration with a minimum amount of loss of telemetry data.

The DSN has also completed the modification of numerous station voltage-controlled oscillators and doppler extractors necessary to make the stations compatible with Pioneer 10 doppler swings. The implementation of the 64-m antenna stations in Australia and Spain is on schedule. The DSN plans to make them available for Pioneer 10 support by July 1, 1973.

The performance of the real-time network support provided to the flight project was satisfactory. The Pioneer Mission Control Team used the DSN-furnished real-time data to monitor and analyze spacecraft and instrumentation health and to make spacecraft configuration adjustments to assure near optimum data return. The Project also calibrated the flight instruments at regular intervals and adapted their performance characteristics to the environment to be measured. Most of the time the Project controlled the mission from ARC using an XDS Sigma 5 real-time processor. Parallel with this capability, the Central Processing System of the MCCC was also operating and providing processed telemetry and command capability to a Pioneer team operating from the Pioneer MCCC area.

The production of continuous data records generated after the real-time operation was constrained by characteristics of the high-speed data lines interconnecting the on-site TCP computers with the Central Processing System located at JPL's Mission Control and Computer Center. The continuity of the System Data Records file established in real-time in the Central Processing System was constrained by a large number of data gaps. These gaps were caused mostly by the burst noises appearing in long high-speed data lines and by characteristics of the software of the computer systems connecting the station with the Mission Control and Computer Center. The DSN attempted to recover most of the larger gaps by recalling specific contents of the on-site Original Data Records. Because of resource, manpower, and budgetary constraints, it was not possible to fill all data gaps of the real-time System Data Records, thus causing a certain number of remaining gaps in the Master Data Records generated for the Pioneer Project by the Mission Control and Computing Center. The extent of small data gaps and the statistical distribution of the DSN-generated System Data Records is under study, and it is expected that the system performance can be improved to minimize the constraints affecting the full data return from some of the spacecraft instruments.

In August 1972, the Pioneer 10 medium-gain antenna reached threshold with the 64-m antenna station in Goldstone. Since that time, the Project has been using the spacecraft high-gain antenna exclusively as the transmission terminal of the downlink telecommunication link. The Project performed numerous DSN-supported automatic CONSCAN spin axis torqueing maneuvers and pointed the spacecraft high-gain antenna back toward Earth whenever the relative drift between the Earth and spacecraft location necessitated such a maneuver.

Figure 1 displays an estimate of the Pioneer 10 and G telecommunications link performance during the next 10 years. The Pioneer 10 geocentric range is shown from launch until the end of 1979. The geocentric range is displayed in astronomical units (1 au = 149.5 million km). The corresponding round-trip light time in minutes is also shown adjacent to the geocentric range scale.

The 26-m subnet will reach spacecraft telemetry threshold at a rate of 64 bps in 1974. In 1976, the spacecraft will fly at Saturn range, and a downlink operation of 256 bps can be provided using the 64-m subnet. Assuming that the radioisotope thermoelectric generators of the spacecraft are still delivering sufficient power to operate the spacecraft telecommunications equipment, Pioneer 10 can be supported with the 64-m antenna stations up to 1979, which is equivalent to a geocentric range of over 19 AU operating at 65 bps. It should be mentioned that if the same stations would use the latest state-of-the-art DSN block receivers with a 3-Hz carrier tracking bandwidth, the spacecraft could be supported by the ground facilities up to 1986, reaching a 30-AU range. The telemetry bit rate would be 16 bps at this time. Under similar circumstances the command threshold using the spacecraft medium-gain antenna and a 20-kW uplink power capability will be reached approximately in 1978 at a range of 16 AU. This range could be expanded to over 70 AU in 1997 if a 400-kW uplink was used. This capability would be somewhat academic in nature because the predicted half-life of the radioisotope fuel is 10 years.

If one assumes that the geocentric range of Pioneer G vs time is similar to the range given for Pioneer 10, the corresponding thresholds can also be obtained from Fig. 1 using the time scale provided for Pioneer G.

Planning for the testing and training necessary for the Pioneer G launch operations is on schedule. A maximum of 20 launch days appears feasible for this second Jupiter-bound mission. A launch window will open on April 4 and close on April 23, 1973. The daily launch windows will be targeted for a minimum of 30 min.

The Pioneer G will be a direct-ascent type. The desired direct trajectory will be accomplished by an Atlas/Centaur burn followed by a TE 364-4 solid-propellant third-stage engine. The launch azimuth will be kept constant throughout the launch opportunity at 108 deg. Beginning in the Atlas sustainer phase (147 s) the trajectories are yawed by guidance as required to obtain the necessary final target vector. The declination angle of the target vector will range from -32.5 to -39.5 deg.

Because of the large negative declination angles, Pioneer G will fly farther to the south than Pioneer 10, and thus the Deep Space Stations located in the southern hemisphere will have long view periods, with a view disadvantage to the northern hemisphere stations. Because of this unfavorable low declination angle, there will be a direct view gap between the initial acquisition station in Johannesburg and Goldstone. To cover this gap the STDN station at Ascension will be used, not only during launch day but for several days after launch until relative improvements of the declination angle will improve the length of view periods at the South African and Goldstone sites.

Documents covering the Pioneer G near-Earth-phase characteristics, station view periods, and the expected coverage capabilities have already been published. Additional information on Pioneer 10 and G is contained in Refs. 1–9.

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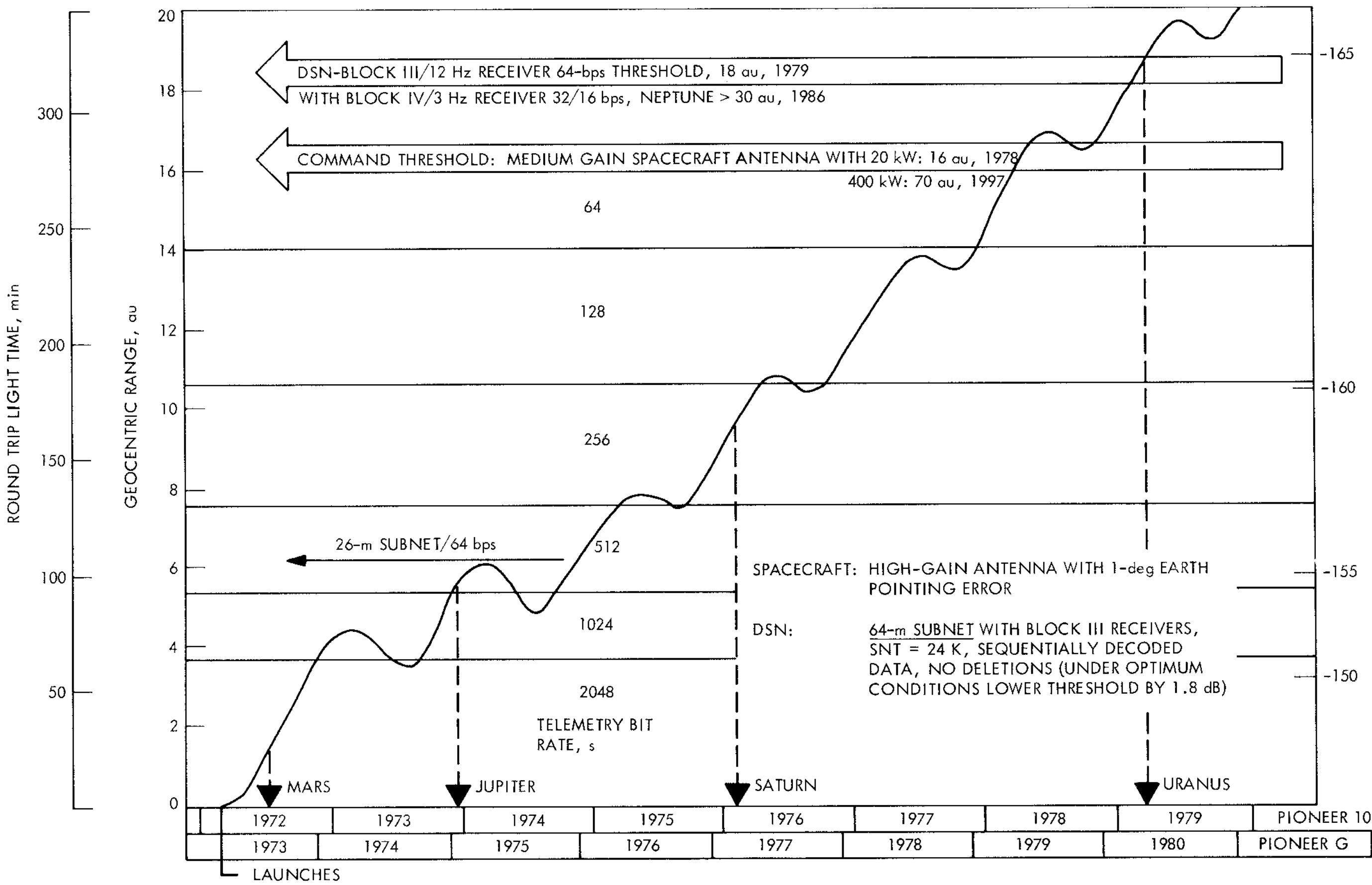

Fig. 1. Pioneers 10 and G telecommunications link performance estimate