Pioneer 10 and 11 Mission Support

R. B. Miller
DSN Systems Engineering Office

Preparations for the Pioneer 11 Jupiter encounter are described, including changes in the DSN implementation from that used for the Pioneer 10 encounter. The reliability of the Ground Data System with respect to commanding the spacecraft is discussed.

I. Introduction

The closest approach of Pioneer 11 to the planet Jupiter will occur on December 3, 1974, at 0522 GMT. The spacecraft will pass within 1.6 Jupiter radii (114,000 km) of the center of the planet with a velocity at closest approach of 48 km/s. The spacecraft will be 732 million km (4.9 AU) from earth. The encounter support period is defined as closest approach ±30 days, which is from November 3, 1974, through January 3, 1975. The 60-day encounter period corresponds to ±380 Jupiter radii from the planet. This may seem like an excessively long encounter period until it is compared with a Venus or Mercury encounter. The time period around Venus or Mercury in a typical flyby trajectory, which would correspond to ±380 planetary radii, would be only ±2 days.

The 60 days around Pioneer 11 Jupiter periapsis passage will have very much the same level of activity as did the period around the Pioneer 10 Jupiter encounter last year. In the 60-day time span, there will be on the order of 8 h a day of critical commanding until the critical encounter phase, which extends from -95 to +95 Jupiter radii (corresponding to November 26 through December 9, 1974), when there will be 24 h a day of critical command activity. The spacecraft will enter the bow shock of Jupiter as early as November 25 and depart the bow shock as late as December 11. The magnetopause will be crossed inbound as early as November 27 and outbound as late as December 8. There will be both a solar and earth occultation. There will again be viewing of the Galilean satellites with several of the onboard instruments; however, there will not be a satellite radio occultation as there was of Io during the Pioneer 10 mission. A smaller number of commands should be necessary for the Pioneer 11 than for the Pioneer 10 Jupiter encounter because several of the problems in the Pioneer 10 imaging photopolarimeter discovered after launch were corrected prior to the Pioneer 11 launch. This means that the total number of commands transmitted in the 60 days of encounter will be somewhere in the region of 12,000 to 15,000.

II. DSN Preparation

After the success of the Pioneer 10 Jupiter encounter, it was agreed with the Pioneer Project that the Pioneer 11 Jupiter encounter should be supported in as identical a fashion as practical. No new implementation was required for the Pioneer 11 encounter. However, some changes were necessitated in the Deep Space Network between the Pioneer 10 and 11 encounters.

First, before the Pioneer 10 Jupiter encounter, there were serious reliability problems with the 400-kW transmitter at DSS 14. Because of reliability concerns, a 100-kW transmitter was installed at DSS 14 prior to the Pioneer 10 encounter. Subsequent to the encounter, the 400-kW transmitter was returned to the vendor and reworked. It was reinstalled at DSS 14 in September 1974. Testing has shown the reworked 400-kW transmitter to be considerably improved in reliability; therefore, the 400- instead of the 100-kW transmitter will serve as the emergency transmitting capability for the Pioneer 11 Jupiter encounter.

In order to prepare for the Viking mission and to support a Saturn radar experiment in December 1974, it was necessary to replace all of the feed cones at DSS 14. The feed cone used for the Pioneer 10 encounter was the polarization diversity S-band (PDS) cone. This cone was replaced in September 1974 with an S-band polarization diversity (SPD) cone, which is more nearly identical to the operational cones at DSS 43 and DSS 63. After temporary installation of the X-band receive only (XRO) cone and associated dichroic plate and ellipsoid required for Viking X/S-band, the XRO cone was removed and the S-band megawatt transmit cone (SMT) reinstalled so that Pioneer would have a backup S-band capability in the event of a failure in the newly installed PDS cone.

During the Pioneer 10 encounter, a problem was discovered with the elevation drive motor gear boxes at DSS 43. The symptom was an extremely noisy operation of the boxes. It was seriously debated at that time whether or not the antenna should be taken off-line during the 60-day encounter period in order to investigate the problem. Instead, to avoid impact on the encounter, it was decided to continue to operate the antenna until after encounter, and emergency procedures were given to the station with instructions on how to cut the shaft on a particular motor if it should happen to freeze up during the encounter. Rework of the elevation drive motor gear boxes was then accomplished at DSS 43 in January and finished in July 1974.

Similar symptoms were also discovered in DSS 63 elevation gear boxes. A meeting was held in late November with Network Operations, the cognizant operations engineer (COE), and the cognizant sustaining engineer (CSE) to assess the risk to the Pioneer 11 encounter if the elevation drive motor gear boxes at DSS 63 were not opened up and repaired. It was decided at that time that, even though it was undesirable to have DSS 63 out of service the month before the actual encounter, the risk was unacceptable to the encounter if the work was not accomplished. DSS 63 was therefore taken off-line for the entire month of October so that the remaining elevation drive motor gear boxes could be removed and reworked.

One of the major activities in preparation for the Pioneer 10 encounter was seeking means of providing the most reliable Command System possible for the encounter period. One part of that effort was an attempt to get command confirmation external to the command modulator assembly operational prior to the Pioneer 10 encounter. Technical difficulties were encountered in the external command confirmation related to phase stability problems in the confirmation loop. For that reason, the external confirmation was not put into operation for Pioneer 10, and instead, a special cable audit was performed of all cables in the command critical path in which the cables were inspected and sealed prior to the Pioneer 10 encounter. Subsequently, the external command confirmation problems were solved, and the external command confirmation which involves feedback from the exciter to the command modulator assembly was put into operation on September 1, 1974; therefore, no special cable audit was performed for Pioneer 11 encounter.

The only change in telemetry or command software at the Deep Space Stations between the Pioneer 10 and 11 encounters was required in order to accommodate a change in equipment numbering at the conjoint stations, DSS 42 and DSS 61. This software change involved using a paper-tape overfill whenever loading the telemetry and command processor (TCP) software for Pioneer support at DSSs 42 and 61.

The configuration control and freeze plan for the Pioneer 11 encounter was essentially identical to that for Pioneer 10, with the dates adjusted to match the change in the time of encounter. A modified configuration control will be put into effect from October 29 (the date of the operational readiness test for the encounter) through January 3, 1975. This modified configuration control involves approval by the DSN Managers, Network Operations Project Engineers, and station directors of any engineering change order (ECO) work to be continued during the encounter period. The configuration of the 64-m stations will be frozen from November 26 through December 9, which coincides with the 24-h critical operations.

III. DSN Command Reliability

The principal concern of the Pioneer Project prior to the Pioneer 10 encounter was the reliability of the total Ground Data System with respect to commanding. This Project concern culminated in a complaint to JPL upper management in February 1973. In response, a JPL "Tiger Team" was formed to study the problem of command reliability. The principal outcome of that activity, rather than any design changes in hardware or software, was an improvement in the procedures associated with the operation of the Command System. Better communications between Project personnel and Mission Control and Computing Center (MCCC) and DSN operators, and the use of timed commands instead of priority commands by the Project, were the major factors that resulted in improved command performance.

Prior to February 1973, the mean time between failure of the Command System was on the order of 24 h. Heavy commanding occurred for only about 4 h every 2 days. At that time, about every other command sequence the Project tried to execute was interrupted by a command failure. After the extensive activity to seek ways of improving command reliability, it was predicted that the mean time between failures for the Pioneer 10 Jupiter encounter period would be on the order of 25 h. These mean-time-between-failure figures are computed based on total track time and not normalized to periods of heavy command activity. The Command System tends to fail or be detected as failed more often when it is under heavy use. Since the encounter period represented almost continuous heavy commanding, and the ordinary cruise activity involved heavy commanding perhaps only 4 to 8 h every 2 days, the prediction of a mean time between failures of 25 h, compared to a prior history of 24 h during cruise, actually represented predicting something like 5 times better performance.

The actual performance during the 60-day encounter was a mean time between failures of 49 h. The total number of commands transmitted during the 60-day Pioneer 10 encounter period was 17,286, and of these commands only seven failed to be transmitted on time. Thus, the mean time between aborts was 205.7 h during the 60 days of encounter. This was achieved even though the mean time between failures was 49 h because of the special procedures that were used during encounter to ensure rapid switchover, in the event of a failure, to redundant system elements. None of the seven failed commands during encounter caused a loss of science data.

In the time period from January 1974 to July 1974, the mean time between failures of the Command System was 66 h. This does not mean that the performance has been better than during the encounter because of the fact that the command activity is much lower. However, it does indicate that the improved command reliability achieved during encounter has not been totally lost in the cruise period since encounter. For this reason, the DSN has confidence that a similar command reliability can be achieved during the Pioneer 11 Jupiter encounter.

Another measure of command reliability is statistics on the total number of system aborts, where an abort is defined as a failure of a command to transmit at the scheduled time of transmission. This does not represent the total number of system failures in that, once an abort occurs, it usually interrupts a sequence of commands, which then have to be replanned and rescheduled. The number of aborts is, however, still a good indication of the Command System performance. Table 1 gives the statistics from launch to August 1974 for both Pioneer 10 and Pioneer 11 and compares them to the commands transmitted during the Pioneer 10 60-day encounter. It can be noted from these statistics that the average command rate in cruise for Pioneer 10 is on the order of 1700 commands per month, and for Pioneer 11 on the order of 1400, while the 60-day encounter period averaged 8643 commands per month.

IV. Test and Training in Preparation for Encounter

Since the Pioneer 11 encounter Ground Data System support would be almost identical to that provided for Pioneer 10, a much smaller number of test and training exercises were planned leading up to Pioneer 11 encounter. A total of 78 h in six tests, including the Operational Readiness Test, was planned in preparation for the Pioneer 11 encounter. These tests were run during actual Pioneer 11 tracks, using the spacecraft as a simulation source in exactly the same fashion as for the Pioneer 10 encounter. Some parts of the tests and the operational readiness test involved the actual commanding of the spacecraft in executing portions of the real encounter sequence. No significant Deep Space Network problems were encountered in any of the tests and training for the Pioneer 11 Jupiter encounter.

Particular items that were of training concern for the Pioneer 10 encounter were the digitally controlled oscillators at DSSs 14 and 43. These are the devices which replaced the vacuum-controlled oscillators and enabled precision tuning of the transmitters and receivers at DSSs 14 and 43 to allow for the tremendous doppler experienced during the Jupiter periapsis passage. There has now been a year and a half of operational experience with these devices, which are used for all tuning, including handovers of missions tracked at DSSs 14 and 43. For this reason, there is more confidence in successful operational use of these devices for the Pioneer 11 encounter than there was for Pioneer 10. Of interest is the fact that ranging data accuracy from 1 to 10 km has been achieved using these devices to do sawtooth ramping and observing the effects of the ramping a round-trip light time after transmission. Such ranging data have been taken once a month and will help achieve the navigation accuracy required for Pioneer 11 to successfully fly past Jupiter and on to Saturn.

Table 1. DSN command reliability

	Pioneer 10	Pioneer 11
Total commands transmitted	65,163	23,266
Total number of system aborts[a]	61	22
Total command reliability, %	99.91	99.90
Data base (launch to August 1974), months	30	17
During Pioneer 10 60-day encounter		
Total commands transmitted	17,286	
Total number of system aborts	5	
Total number of procedural aborts	2	
Total command reliability, %	99.96	

[a]Represents failure of a command to transmit at time of transmission.