Pioneer 11 Mission Support

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The cursory scientific results of the Pioneer 11 Jupiter encounter are described. The DSN performance during the 60-day encounter is described with emphasis on the Command System performance.

I. Pioneer 11 Jupiter Encounter Cursory Scientific Results

The principal differences between the Pioneer 10 and 11 encounters important to the science observations are: First, Pioneer 11 went much closer to the planet; second, the outbound leg of the trajectory occurred at a different local time, that is, at a different phase relative to the Sun and out in a much higher magnetic latitude than Pioneer 10; and, third, repeat observations at a different epic in time which will help differentiate between spatial and temporal fluctuations in the observed phenomenon.

As with the Pioneer 10 Jupiter encounter, Pioneer 11 detected multiple-bowshock crossings as it approached the planet Jupiter. It is therefore indicated that extensive fluctuations in the magnetosphere of Jupiter are most likely a common occurrence. Jupiter has very large moons, which are very close to the planet compared to the planet's radius. For this reason, there was considerable interest before the Pioneer 11 encounter as to whether there were interactions between the moons and the magnetosphere. The spacecraft trajectory carried Pioneer 11 very close to the flux tube of the satellite Io. An interaction of the magnetosphere with the orbit of Io was not immediately apparent in the helium vector magnetometer data; however, there did appear to be noticeable effects due to Ganymede and Callisto. Since the Pioneer 11 trajectory swept out a much wider range of longitude than Pioneer 10, it is expected to have a much better map of the magnetic field, in particular the dipole component of the magnetic fields orientation, location, and magnitude, than was possible with Pioneer 10 data alone. There were indications from the measurements by the dual flux-gate magnetometer that the magnetic field of the planet closer than 3 Jupiter radii could not be successfully represented by an offset dipole but was more complex, and that tentative modeling of the more complex field could help explain the decimetric radio emissions from Jupiter which are observed on Earth.

The inner core or dipole region is where there is strong trapping of particles. For high-energy protons in the region greater than 35 million electron volts, Pioneer 10 measured a peak at about 3-1/2 Jovian radii, and the Pioneer 10 data ended with the downward slope after this peak. Pioneer 11 went much closer and measured the same peak as Pioneer 10, and there are indications of a second peak closer in to the planet. Similar peaks were observed on the way in and the way out, thus indicating that the peaks are caused by a contained group of particles in the magnetic field which form a shell-like structure around the planet. These protons are the same kind of energy as is produced in a cyclotron on Earth, but produce no radio emission and are therefore undetectable except by *in situ* measurements. The inner peak for low-energy protons had an intensity of approximately 150,000,000 protons per square centimeter per second. This core structure of charged particles appears to be one of the more stable features of the planet Jupiter.

Measurements of the electrons in the core region around Jupiter in the energy spectrum of those electrons capable of producing radio emissions indicate perhaps 10 times the abundance as was expected based on Earth observations of radio emissions. Proper modeling of this electron content versus the radio emissions is very important to astrophysics since ground-based measurements of radio emissions are used to deduce electron content in distant objects.

Concentration of high-energy protons and electrons around the plasma sheath discovered by Pioneer 10 was confirmed by Pioneer 11. It appears that there is an acceleration mechanism in effect around the plasma sheath region. The 10-hour periodicity in the radiation intensity, which was assumed to be tied more closely with the equatorial plane passage of Pioneer 10, was also evident in the higher latitude data received by Pioneer 11. A sweeping effect of the inner moons indicated by Pioneer 10 was reconfirmed by Pioneer 11. There is also confirming evidence that bursts of electrons and protons seemed to escape Jupiter's magnetosphere. This is implied by the observation of the 10-hour periodicity in particle count as the spacecraft approached the magnetosphere as early as 6 months before closest approach to the planet.

The two-month long imaging of the planet Jupiter enabled viewing changes in the visible features of that time scale, and the year-spacing between Pioneers 10 and 11 enabled seeing longer-term changes in the visible features. Pioneer 11 appeared to show a little more structure in the red spot and crisper definition of flow around the red spot. The convective plumes of rising gas about the equator were still present in the Pioneer 11 pictures.

Because of the change of Pioneer 11 to a Saturn trajectory, the ultraviolet photometer was not able to view the planet Jupiter during this flyby. However, it did view the Galilean satellites of Jupiter, and preliminary indications are that the hydrogen cloud observed associated with Io during Pioneer 10 was confirmed as still existing, whereas it appears that Ganymede and Callisto do not have a hydrogen cloud associated with them.

The meteoroid detector measured a higher concentration of small particles in the Jupiter environment than in interplanetary space, and comparison of the Pioneer 10 and 11 data indicates that these particles are being focused into Jupiter from their solar orbits and are not in orbit around the planet.

The occultation experiment seemed to be highly successful again, with all open- and closed-loop data successfully recovered. The experimenter expected to see less multipath due to layering in the Pioneer 11 data than in the Pioneer 10 data because of the different trajectory. Rather surprisingly, though, the Pioneer 11 data seemed to be even more complex than the Pioneer 10 and will require extensive analysis in order to draw firm conclusions.

The celestial mechanics experiment received very good data. The nature of the Pioneer 11 trajectory meant that the possible gravitational effects of the planet Jupiter were observed over much wider latitudes, and indications are that, from a gravitational standpoint, Jupiter is a very smooth body in hydrostatic equilibrium; that is to say, no evidence of mass concentrations was observed. The perturbations of the trajectory due to the large satellites of the planet Jupiter will enable accurate determination of the masses and estimates of the densities of the four Galilean satellites. Preliminary results indicate that the two inner satellites, Io and Europa, appear to be denser than the two outer Galilean satellites, Ganymede and Callisto. This will have implications as to what their formation process may have been.

II. DSN Performance During the Pioneer 11 Jupiter Encounter

The overall DSN performance during the Pioneer 11 Jupiter encounter was at the same high level of reliability as was demonstrated during the Pioneer 10 Jupiter encounter despite the fact that launch of the Helios-A mission occurred only 7 days after the closest approach of Pioneer 11 to the planet Jupiter.

The most significant non-command problem experienced by the DSN was noise at DSSs 63 and 43 a few weeks prior to the periapsis passage. The problem at both stations is referred to as "noise spikes," which is the term used for an increase in receiver noise due to some kind of return of the transmitted signal. The usual real-time method around the problem is to reduce the transmitter power and therefore the power of the returned noise. This workaround was acceptable during the Pioneer far encounter because of the large uplink margin that the spacecraft enjoys at the Jupiter distance. This problem was, however, a concern for the near-encounter period when possible radiation effects on the spacecraft could require high transmitter power. Noise spikes can be caused either by problems internal to the microwave system or by external reflections or arcing on the actual antenna structure. The problem at both stations was reduced to an acceptable level before near encounter. The problem at DSS 43 was isolated to a section of waveguide, which was replaced. The corresponding section of waveguide had been replaced at DSS 43 previously due to noise spiking problems. (As a consequence, a structural design change is in process for this section of waveguide.) The noise-spiking problem at DSS 63 was reduced to an acceptable level by removing the dichroic plate and ellipsoid from the top of the cones. There were no noise-spiking problems during the rest of the encounter after the above action was taken.

As with Pioneer 10, the biggest concern for the total Ground Data System was command reliability. This is the case with the Pioneer 10 and 11 missions because of the fact that both missions involve flying an extremely complex planetary encounter sequence without the aid of an on-board programmer. A tremendous number of commands are required to operate the encounter sequence, with the majority of the command requirement due to a single instrument, the Imaging Photo Polarimeter (IPP) (the details of the IPP instrument's operation and the resulting large number of commands required are described in Ref. 1). Pioneer 11 required 28% fewer commands than Pioneer 10, mostly due to better performance of the IPP instrument, where problems with gain control and stepping which existed on Pioneer 10 were corrected on the Pioneer 11 instrument prior to launch.

The overall command reliability of Pioneer 11 is compared to Pioneer 10 in Table 1. In this table, the reliability is compared using the total number of DSN aborts, where an abort is defined as a failure of a command to transmit in real time due to a DSN-caused failure or operator error. Of the 17,286 commands transmitted during the Pioneer 10 60-day encounter period, there were seven DSN aborts, resulting in a total command reliability of 99.96%. The figure for Pioneer 11 is comparable in that there were 12,358 commands transmitted during the 60-day encounter period of which eight were aborted due to a DSN problem, resulting in a total command reliability of 99.94%. Of those eight failures, four were caused by the same type of anomaly at DSS 63, which resulted in elapsed timed commands. This failure occurred during several DSS 63 passes in November until the problem was finally isolated to a timing problem in a particular Telemetry and Command Processor.

The total number of real-time aborts is not a complete measure of the Command System reliability and its effect on the Project execution of the encounter sequence. This is because once the failure has occurred, the Project ceases trying to transmit commands until the Command System is restored. In order to get a picture of this aspect of the Command System reliability, the total number of failures (whether they caused an abort or not), along with the mean-time between failure and the mean-time to recover from the failure, is listed in Table 2. This table lists the statistics for four different levels of support. Levels of support are defined in advance as the means of committing to the Project the amount of redundancy and the amount of effort that will go into a particular track. Level 1 is the highest level of redundancy the DSN can provide, where the redundant telemetry and command strings are loaded and are processing simultaneously with the string that is supporting the track, and a maximum effort is made by station personnel to recover rapidly in the event of a failure in the real-time string. A 6-minute recovery from a failure in redundant equipment is committed during Level 1 support. As the table shows, Level 1 support was committed for just the three passes surrounding periapsis, and there were no Command System failures during that period. Level 2 support is essentially the same equipment configuration as Level 1 support, but the recovery requirement is relaxed to less than or equal to 20 minutes. From Table 2 one can see that there were 144 passes where the committed Level 2 support was provided, and during those passes there were 11 failures in the Command System with a mean-time to restore of only 6.45 minutes, well within the 20-minute requirement. There were also 26 passes labeled as Level 2-F in Table 2, where the Level 2 redundant configuration could not be completely provided because of failures in the redundant equipment. Fortunately, during none of these passes was there a failure in the prime on-line equipment. Level 3 support does not require that the backup string be loaded and running during the pass and relaxes the recovery time requirement to 30 minutes or less. The table shows that there were 36 passes with Level 3 support in which only 2 failures occurred, and the mean-time to recover was 22 minutes, which also meets the recovery requirement. (Statistical data were extracted from Refs. 2, 3, and 4.)

As was the case for the Pioneer 10 encounter, during the Pioneer 11 encounter the overall performance of the Ground Data System, and in particular the DSN portion of the Ground Data System, was such that there was no compromise in the science return during the 60 days of encounter due to a Ground Data System or DSN problem.

References

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2. Hoffman, B., *Command System Reliability During Pioneer 11 Encounter*, 421-PF-CMD-050, Jan. 21, 1975 (JPL internal report).
3. Frampton, R., Hoffman, B., and Tucker, W., *Command System Monthly Report for November 1974*, 421-PF-CMD-048, Dec. 10, 1974 (JPL internal report).
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Table 1. Command reliability during Pioneer 10 and 11 Jupiter encounter

Mission	Total commands transmitted during 60-day encounter	Total number of DSN aborts[a]	Total command reliability,[b] %
Pioneer 10	17,286	7	99.96
Pioneer 11	12,358	8	99.94

[a]Defined as failure of a command to transmit in real time due to a DSN-caused failure or error.

[b](Total commands − number of aborts)/total commands.

Table 2. Command system reliability during Pioneer 11 Jupiter encounter

Support level	Number of passes	Number of failures	Mean time between failures, h	Mean time to recover, min	Reliability,[a] %
1	3	0	–	–	100.00
2	144	11	93.8	6.45	99.89
2-F[b]	26	0	–	–	100.00
3	36	2	153.9	22	99.76

[a](Track time − total time failed)/track time.

[b]Failure to provide committed Level 2 configuration.