Voyager Support

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This is a continuing Deep Space Network report on tracking and data acquisition for Project Voyager. This report covers the period from January through May 1978.

I. Voyager Operation

A. Status

Both spacecraft successfully passed through the asteroid belt which lies between the orbits of Mars and Jupiter. As of May 1978, Voyager 1 was 555 million kilometers (348 million miles) from Earth, traveling with a velocity of about 19.9 kilometers (12.4 miles) per second relative to the sun with one-way communications time of 30 minutes and 45 seconds. Voyager 2 was more than 535 million kilometers (332 million miles) from Earth, traveling at about 18.8 kilometers (11.7 miles) per second relative to the sun, with one-way signal time of 29 minutes and 52 seconds.

Both spacecraft have experienced problems that required special support effort by the Deep Space Network (DSN) personnel. DSN personnel worked closely with project personnel in determining the best way to extract the maximum capability of equipment and facilities to enhance the probability of meeting project mission objectives.

B. Spacecraft Problems

1. Voyager 1. On February 17, when DSS 63 acquired the Voyager 1 spacecraft, it was discovered that 40 b/s of engineering data was being transmitted through the low-gain antenna (LGA) instead of the 1280 b/s through the high-gain antenna (HGA) as expected. This mode indicated that the failure protection algorithm had been entered. The data was erratic because the link performance was at threshold; to strengthen the downlink signal, it was decided that the S-band ranging would be turned *off.* It was determined that the spacecraft was in roll inertial, sun acquired, but not in celestial cruise. Commands were sent to capture Canopus, and the HGA was automatically selected. A programed Cruise Science Maneuver (CRSMVR) had been aborted, apparently caused by some form of gyro-induced error since sun sensor data obtained from the playback indicated a displacement in solar position at the culmination of each of ten 360-degree yaw turns. A group of analysts examined the data in detail and determined that the spacecraft attitude at the end of the 3600-degree yaw turn was about 24.50 deg short of the predicted orientation. This resulted in the sun being outside the sun sensor field of view, causing the CCS to abort the remaining portion of the maneuver. A sun search was automatically initiated and the sun was reacquired.

The attitude error was caused by the use of the design value of the gyro scale factor in the Maneuver Analysis Program SET (MAPS) instead of the actual measured scale factor values of the gyros. It was noted that the 24.50-deg turn error represents a deviation in scale factor values from the design value of approximately 0.37%, which is well within the allowed tolerance and in no way associated with substandard gyro performance. The improper gyro scale factor conversion values in the ground software that caused the problem has been corrected by including the appropriate value for each gyro in the generation program.

On February 17 the Plasma Science principal investigator indicated that the sensitivity of the main cluster of the three plasma detectors had degraded significantly and the instrument was not able to detect positive ions to a level as low as before. Real-time commands were sent first to calibrate the plasma instrument in all gain states (without success in the main mode) and second to "power on reset" (POR) the instruments twice, hoping to recapture the sensitivity (again without success).

In early March further degradation was observed in the ailing main detector, and it appeared that the Jupiter encounter objectives would be affected as well as the cruise measurements. The instrument's side detector continued to operate well.

A series of sensitivity tests were performed in March and April, as was a reset/diagnostic test. There appeared to be a threshold on positive ion measurements, causing the output data to be shifted such that only the peaks of the plasma curve appear. MIT is studying the problem to determine how this could happen and what could be done.

During a calibration of the scan platform on February 23, the azimuth actuator failed to reach its commanded position. This resulted in a scan slew abort, when the Attitude and Articulation Control Subsystem (AACS) detected the slew in progress at the end of 60 minutes. The actuator failed to move appreciably when commanded to the safe position by the scan slew abort routine. The Central Computer and Sequencer (CCS) scan command and scan abort routines were inhibited and the cameras placed in a safe state as a precautionary measure until the problem could be evaluated.

On March 17, a test sequence of slews was commanded and executed which resulted in the platform moving as desired. The slews were performed at the low rate to create maximum torque from the actuator. The first slew appeared to move at an intermittent rate but two additional slews were executed flawlessly.

During the week of March 24-30, 1978, the scan platform was commanded through several slew sequences, which exercised various directions, magnitudes and rates of motion in the region of the science preferred position. During the following week the testing included periods with the scan platform heater *off* and *on*. Further testing is continuing with a plan to define scan platform pointing region limitations, if any.

On 18 May the gyros were turned on by an onboard sequence for calibrations to be performed on May 19. During the GYCAL it was recognized that there was no command in the sequence to turn the gyros *off*. A decision was made to leave the gyros on through the ASCAL to be performed on May 26 and use this opportunity to obtain long-term gyro drift data.

An LECP sun interference test was performed on May 23 by ground-commanding LECP full scan mode. It was found that the sun causes excessive noise in this mode. The LECP was then ground-commanded to the reduced scan (normal) mode.

2. Voyager 2. On February 25, the Photopolarimeter (PPS) principal investigator advised that the PPS filter wheel was stepping erratically. It was requested that the instrument be safed and then turned off until further analysis could be performed. The polarization analyzer wheel had previously indicated that it was stuck. The onboard command sequence resulted in the filter wheel and analyzer wheel being placed in positions other than those which would have resulted from the safing commands. Analysis indicated that not only was the filter wheel stepping erratically prior to instrument turnoff, but that the analyzer wheel seemed to have become unstuck and responded to the safing command. On March 2, a series of commands were sent to see if the erratic stepping continued, but during the testing nominal stepping was observed.

On April 5, 1978, Voyager 2 (spacecraft 32) entered its command loss routine, which switched to the spacecraft secondary receiver (receiver number 2). The receiver switch was the result of the protection algorithm's normal function since the spacecraft did not receive commands within 7 days. The spacecraft remained in this configuration for 12 hours, and during this period many attempts were made to attain two-way lock on receiver number 2. All attempts failed because the voltage-controlled oscillator tracking loop capacitor had failed, but this was not known at the time. Preliminary analysis of the data, about 24 hours after the failure, indicated that the tracking loop capacitor may have failed.

After 12 hours had elapsed and the spacecraft's command loss time had not been reset (no command capability), the spacecraft reentered the command loss routine and switched back to receiver number 1. Receiver number 1 attained two-way lock and several commands were transmitted through the main receiver, thus causing a reset of the 7-day timer. However, about 30 minutes after the switch, an unknown failure in the receiver caused excessive current, which appeared to have blown the receiver fuses. The spacecraft remained on the main receiver and was unable to receive commands from Earth. However, the 7-day timer was set to automatically switch to the secondary receiver on April 13, at which time attempts would be made to command the spacecraft in spite of the failed capacitor.

The intervening period was a period of intense activity focusing on developing a strategy to permit commanding the spacecraft through the secondary receiver with a failed tracking loop capacitor. The DSN participated in developing the uplink sweep strategies and overall command strategy within the capabilities of the facilities available.

The loss of the radio frequency tracking loop capacitor in receiver 2 (secondary receiver) meant that the receiver could be acquired (i.e., phase coherency established), but the tracking loop could not maintain lock as the receiver frequency shifted due to the doppler effect. It was determined, by testing a test receiver with the capacitor shorted, that the bandpass of the Voyager receiver was approximately 200 Hz (S-band). It was also determined, by testing, that spacecraft command detector lock could be achieved and commands received while on the command subcarrier (512 Hz from the carrier), thus effectively widening the command window.

With this information and following the guideline that at least one command must be received correctly by the spacecraft during a sequence, a sweep profile and test plan was developed. This plan called for one wide sweep of best-lock frequency (XA)±1500 Hz (S-band), equivalent to sweeping through XA and at a rate of 2.4 Hz/s (S-band). During these sweeps, commands would be transmitted from DSS 63 at 15-s centers, the interval computed to give the highest probability of command reception. If these sweeps were unsuccessful, a larger sweep (XA plus or minus 5000 Hz) at a slower tuning rate (1.92 Hz/s) would be performed.

If any of the initial sweeps were successful, the receiver best-lock frequency would be computed using available information on the downlink (lockup time, time of peak AGC, etc.). The station would then transmit this frequency, corrected for doppler, and maintain lock by ramping to compensate for doppler. Commands could be transmitted during this period. This plan was successfully tested with DSS 63 on a training exercise on April 11.

On April 13 this Voyager 2 recovery sequence was initiated by DSS 63. Within 55 minutes it was confirmed that commands had been received through receiver 2. Analysis indicated that the receiver had been acquired during the first sweep with the actual best-lock frequency slightly more than 750 Hz (S-band) from the predicted frequency.

The preplanned command sequence was entered approximately one hour later. The procedure used consisted of updating the best-lock frequency and performing a short sweep every 90 min for the remainder of the pass. Following the sweep, DSS 63 ramped the uplink to compensate for doppler while transmitting blocks of 24 commands. This was done six times, to insure that six different commands were received. By the end of the track, the spacecraft receiver lock had been held for a total of more than 4 hours, proving that the receiver could be acquired and the spacecraft commanded.

Following the initial receiver 2 acquisition, many plans were made to compensate for the loss of tracking capability. The procedure used during 26-meter tracking involved turning on the transmitter at Track Syn Freq (TSF) and allowing the earth rotation induced doppler to sweep the uplink signal through the acquisition bandwidth of the spacecraft receiver.

The characteristics of the spacecraft receiver AGC and the downlink signal during these periods were unlike anything experienced on previous programs. Essentially what occurs is that as the uplink signal approaches the spacecraft receiver acquisition range, the AGC circuit detects the signal and switches the downlink reference to the voltage control oscillator. At this time the receiver is not in lock and the indicated spacecraft AGC is 20 dB below predicts. The downlink reference is now the free-running VCO; as a result the doppler is meaningless (neither one-way nor two-way) and the downlink signal is corrupted by VCO noise. Following the initial AGC acquisition the indicated uplink AGC increases steadily for about 40% of the total two-way period. The AGC then ramps up rapidly to about 8 dB below predicted level, at which time the spacecraft receiver apparently achieves coherent loop lock. At times the indicated spacecraft AGC goes to zero during this ramp. Once the loop is locked, the indicated spacecraft AGC follows a fairly smooth pattern for the remainder of the two-way period. The doppler prior to the first AGC is good one-way Ultra Stable Oscillator (USO) doppler. The doppler between first AGC and loop lock is no good. The doppler from the loop lock to loss of AGC is good two-way doppler. The doppler following loss of AGC is good one-way.

The downlink AGC and SNRs are affected by the VCO phase jitter following the first spacecraft AGC acquisition. At that time the spacecraft selects the VCO as the downlink reference even though phase lock has not been achieved. As a result the downlink is corrupted by the phase noise of the free-running VCO. This is manifested by a decrease in the symbol and bit signal-to-noise ratio. As the uplink signal approaches the loop acquisition range, the phase noise becomes worse since the loop is now attempting to acquire and is slipping cycles. During the steep AGC ramp just prior to acquisition, the loop is in a state of continuous cycle slipping and the resulting phase noise becomes so bad that the indicated downlink AGC is also degraded about 8 dB. Following loop lock, the downlink AGC and SNRs return to normal levels and stay there throughout the remainder of the two-way period.

Voyager 2 was successfully commanded by a 26-meter station using this procedure on April 18. The receiver was locked as predicted. During the period 24 duplicate commands were sent. Twenty of the commands were received and executed by the CCS. Receiver lock tests were performed daily with the spacecraft to determine the Project's capability to predict and demonstrate receiver and command detector lockup. On April 25 the spacecraft VCO rest frequency unexpectedly increased by 182 Hz over what it had been on the previous 12 station passes. Efforts continued to better model the receiver VCO, so that the rest frequency could be predicted to the accuracy of plus or minus 100 Hz required for commanding.

A trajectory correction maneuver (TCM) was performed on May 3. This was the first Voyager demonstration of a TCM tweak load one day prior to the TCM. Due to the uncertainty in commandability, the enable command was sent about 14 hours earlier than for previous TCMs. Two-way noncoherent (TWNC) mode was entered prior to the TCM to use the USO for downlink frequency. The TCM was executed successfully.

A series of frequency sweeps was started and continued for about 30 hours after the TCM to measure the VCO as a function of temperature change. Telecommunication analysts were able to provide good predicted frequencies so that the receiver maintained lock to allow commanding the TWNC *off* at the end of the sweep period. Planning continues for the continued operation and navigation of the spacecraft through its encounters.

The Voyager 2 CCSL B207 was successfully uplinked to the spacecraft on May 24. The 33 min load was sent twice, since only about 60% of the commands were accepted by the CCS. The lack of a VCO frequency measurement on the tracking pass prior to the load was the primary cause of the command difficulties.

II. Station Operation

A. New Capability

The new MDA software (DMK-5106-OP-C), which provides the TRK 2-14 radio metric data format capability, was distributed to the field on February 27, 1978. This format was basic to the new interface for radio metric data to the Project. The new interface is between the DSN and the Project in the form of an Intermediate Data Record (IDR) and replaces the MCCC Project Tracking Tape (PTT) as the Project interface. The change was necessitated by the MCCC Mark III Data System, in which the IBM 360/75 computers were replaced by Modcomp minicomputers. Under the MCCC Mark III Data System concept, radio metric data is not processed by MCCC.

A series of training/test passes was authorized so that the stations, network data processing terminal and project navigation team personnel could become familiar with the new operation and interface. The normal problems associated with a new operation and software were experienced and appropriate procedures generated to alleviate the problems. On May 1 support of Voyager 1 was converted to the new interface and on May 6 support of Voyager 2 was converted. Simultaneously with the implementation of the MDA software, the associated Planetary Ranging Assembly (PRA) software (DIR-5125 OP) became operational.

DSS 11 was decommitted from Project support and started the Mark III Data System (MDS) implementation on January 15, 1978. The installation and subsystem testing was completed on March 22, 1978. On March 23 the Operational Verification Tests (OVT) were initiated. The minor problems encountered during these tests were corrected and DSN Engineering Interface Verification Tests (DEIVT) were conducted on April 3 and 6, 1978. The Performance Demonstration Test (PDT) was conducted on April 11 and the Ground Data System (GDS) Test on April 17. The GDS test was only partially successful and was rerun on May 12. Interspersed with the tests were demonstration passes during which the Voyager spacecraft were tracked and the data carefully analyzed. The station was put under configuration control on April 26 and assumed its Project support role along with the other 26-meter stations.

B. Operational Support

The support of the Voyager 2 emergency placed an extra burden on the DSN operations in the areas of planning, tracking analysis and real-time operations. Approximately 120 scheduling changes were required in order to meet the station support requirements for real-time and analysis activities. Procedure changes were required which could not be fully tested or refined before being put into the operational support category, placing the DSN in a higher risk situation. An extra requirement was placed on predict generation to meet the increased activity. Most of the activities will continue, especially in the planning and analysis area, to insure that appropriate procedures are developed for station handovers, ranging, doppler and commanding for the immediate real-time support activity as well as for the future Jupiter encounter operation. Although additional burdens are placed on the Deep Space Station Operations, and in some cases the accomplishment is difficult because of manual intervention, it appears as if the DSN can meet its commitment to successfully support the Voyager Project during the encounter of Jupiter.

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Bibliography

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