Voyager Mission Support

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This is a continuation of the Deep Space Network report on Tracking and Data Acquisition for Project Voyager. This article covers the period of November 1980.

I. Introduction

Voyager 1 completed the Far Encounter 2, Saturn Near Encounter and started the Post Encounter phase of its mission operation.

Voyager 2 continued in the Jupiter-Saturn Cruise Phase of its mission operations.

II. DSN Support

By both DSN and Voyager Project standards, the Deep Space Stations and Network Operations Control Team provided excellent professional support for the Voyager 1 encounter period.

A. Navigation Cycle

The Voyager 1 Far Encounter began with a dual Navigation Cycle. During a dual Navigation Cycle, each 64 meter station tracks the spacecraft at least twice with DSS 43 accomplishing three passes as this station starts and ends the cycle. This Navigation Cycle had the primary function of providing precise orbital determination data in preparation for a final trajectory correction prior to closest approach to Titan. During this Navigation cycle, all 34/64 meter stations tracked in an array configuration to improve telemetry data return of critical Optical Navigation and Imaging information while obtaining the radio metric data.

Near Simultaneous Ranging (NSR) was accomplished by DSS 63/43 during their common view period. A unique geometry, zero declination, existed at Saturn Encounter for Voyager. This geometry made it impossible to solve for the spacecraft declination by fitting doppler data as it is normally done in the orbit determination process. The alternate technique for deriving the declination is to use range data taken almost simultaneously from stations at widely separated latitudes and triangulating to solve for the declination angle. This dependence upon range data required that highly accurate range measurements and range delay calibration information be provided by the stations to the Navigators and Radio Scientists. To accomplish this, the stations were required to make numerous uplink transfers to provide data redundance for data confidence. The standard DSN transfer cannot be used for these NSR uplink transfers, since the normal tuning pattern changes the phase relationship of ground reference and received range codes, causing loss of range data from the transferring station for the round-trip light time (RTLT).

To avoid the loss of the NSR data, an alternative transfer tuning procedure is used. This procedure, upon completion of all required tuning, restores both the frequency and code phase relationships required for good ranging through the RTLT following an uplink transfer. This procedure takes advantage of the programming and precision tuning capabilities of the synthesizer controllers available at the 34- and 64-meter stations. The procedure calls for both incoming and outgoing DSSs to execute precision symmetrical tuning patterns between specified limits, at fixed rates, and at specified times. Figure 1 depicts an NSR transfer and related events. It can be seen that the transfer requires four ramps to achieve the desired symmetrical tuning pattern. All ramps are done at the same rate, the initial direction of the first ramp being dependent upon whether the estimate of the spacecraft best-lock frequency corrected for doppler (XA) is above or below the Tracking Synthesizer Frequency (TSF). Since the XA is a doppler dependent frequency, it constantly changes; therefore, the frequency for any given transfer time is different. The total time to execute the entire transfer and tuning pattern is approximately five minutes.

B. Radio Science OVTs

On 3 and 4 November, the last Radio Science Operational Verification Tests (OVTs) were conducted with DSS 43 and 63, one station on each day. These OVTs included the changes in countdown procedures, calibration parameters, and configuration requirements as revealed by the previous OVTs. The OVTs also included a voice interface capability between the Radio Science (RS) Team at JPL and the DSN Radio Science representative at DSS 43 and 63. It was deemed advisable to have a representative from JPL at the stations during the critical RS activity to assist the station personnel and to interface with the RS Team to discuss problems and requirements in real-time. This interface was limited to six areas of operation:

(1) Selection of ODA predict sets.

(2) Selection of ODA time offsets.

(3) Selection of ODA frequency offsets.

(4) Selection of SSI display channels.

(5) Initiating, extending, and restarting ODA run/idle modes.

(6) Selection of PPM Noise diode and integration times.

On 5 November, the RS ORT #5 was conducted with both DSS 43/63. This ORT simulated the Saturn Encounter Operation within the station overlap period. The ORT required the configuration as specified for the upcoming encounter and the data requirement applicable for the actual period. The ORT was a success and the stations declared ready for the occultation experiments.

C. TCM-A9

On 6 November, a Trajectory Correction Maneuver (TCM-A9) was performed to provide the necessary adjustment to the spacecraft flight path to ensure the closest approach to Titan without danger of impacting the satellite. The maneuver required the spacecraft to rotate off earth point, resulting in a loss of the downlink while the TCM "burn" was being accomplished. After the trajectory change, the spacecraft returned to earth point. DSS 63 had prepared their high-power transmitter for emergency support. The high-power transmitter would provide an added probability of commanding the spacecraft to the proper orientation if required. However, DSS 63 reacquired the downlink at the appropriate time, and data evaluation confirmed the maneuver was a success.

D. Post-TCM Navigation Cycle

On 7-10 November, a post-TCM dual navigation cycle was supported to provide the new trajectory information for orbit determination. During this Navigation Cycle NSR were conducted by DSS 14/43 and DSS 14/63 during each common view period for the more precise zero declination information. Arraying by the 34/64 meter stations was likewise accomplished during their tracking periods. Optical navigation pictures to provide additional refinement were periodically received during the period.

E. Cyclic Phase

On 10 November, the spacecraft data mode entered the encounter cyclic phase during which the telemetry formats and bit rates changed frequently. This mode allowed the several different imaging formats, playback of recorded data and various general science formats to be transmitted in bit rates from 19.2 through 44.8 kbps in rapid succession. This mode required the stations to be alert to the sequence and reinitialize the TPAs for the bit rate changes to insure that the telemetry strings were locked up and good data was processed without undue delay. This mode of operation continued throughout the closest encounter period.

F. Contingency Operation

On 11 November (DOY 316) at 1125Z, with the acquisition of Voyager 1 by DSS 14, the requirement was imposed on the 64-meter network to countdown the high power transmitter (100 kW) and have it on standby for contingency operation. Under these circumstances, the 64-meter stations performed their normal uplink functions with the normal transmitter, using 10 kW uplink power from the 20 kW transmitter, with the option at the request of the Project to switch to the backup high power transmitter to support contingency plans. This requirement continued until 14 November (DOY 319) at 2115Z with the conclusion of the DSS 14 tracking period. No problems were encountered that required the implementation of contingency plans.

G. Titan Encounter

On 11 November, preparations began for the closest approach of Titan. One of the first actions was to reorient the spacecraft tracker from Canopus to Miaplacidus to avoid obscuration of Titan. This reorientation was accomplished by a roll turn while completing a Fields and Particles Measurement. This maneuver required DSS 14/12/43/42 to track the downlink carefully in case the spacecraft did not complete the proper reference and the downlink became lost. Although the signal fluctuated, the stations maintained lock and the maneuver was completed successfully.

The Radio Science Experiment with the Titan occultation was diametric so as to allow the deepest possible atmospheric penetration of the ray path to Earth. The duration of the occultation was only 12 minutes. The objectives were:

(1) Measure atmospheric temperature and pressure as a function of height and contribute to the determination of atmospheric constituents.

(2) Investigate the microwave absorbing properties of the atmosphere.

(3) Determine ionospheric profiles and plasma densities at the entrance and exit location on Titan.

(4) Measure the radius of the solid surface and help determine the mean density of Titan.

The ground events for the occultation occurred primarily at DSS 63. However, DSS 62 provided S-band, closed-loop occultation backup coverage and DSS 61 performed dual-frequency, closed-loop tracking of Voyager 2 in order to obtain independent measurements of the solar plasma for calibration of the occultation data. DSS 63 tracked Voyager 1 with CONSCAN OFF and a fixed subreflector focus position so as to remove station-induced signal variations. The downlink was recorded on the mediumband, open-loop receiver system in the two-channel configuration. Ionospheric data was obtained from the closed-loop receiver system. A signal profile was provided by the Project and during the operation it was found to be fairly accurate.

H. Saturn Encounter

On 13 November, the closest approach to Saturn was made. Again, the major activity was concerned with radio science occultation data. The occultation began approximately 100 minutes after Saturn's closest approach and lasted for about 90 minutes. The spacecraft performed a limb-tracking maneuver for the majority of the occultation, with the spacecraft orientation not being changed for a 35 minute period for the benefit of the UVS Sun occultation exit measurement. The limb-tracking maneuver was designed to keep the high-gain antenna pointed at the virtual image of the Earth, as that image moves around the limb of Saturn. (The virtual image of the Earth is that point where, at a given time, the radio raypath can be refracted around Saturn and back to Earth.)

The objectives of the Saturn occultation experiment were to:

(1) Measure atmospheric temperature and pressure as a function of height and help determine the hydrogen-to-helium ratio.

(2) Investigate the microwave-absorbing properties of the atmosphere and determine the ammonia abundance.

(3) Determine the structure and characteristics of Saturn's ionosphere.

(4) Measure the oblateness of Saturn.

(5) Investigate turbulence and waves in the neutral atmosphere.

(6) Investigate ionospheric irregularities.

(7) Interpret the measured dynamics for indications of large-scale motion and energy flow in the atmosphere and ionosphere.

The ground events for the Saturn occultation occurred primarily at DSS 43 for the entrance measurement and at DSS 63 for the exit measurement. Due to general mission planning considerations and science trade-offs, which were made during the trajectory-selection process, DSS 43 set time was about one minute before occultation exit and DSS 63 rise was about halfway through the occultation. This geometry necessitated the special low elevation tracking procedure designed to maintain accurate pointing during the period of extreme signal dynamics. DSS 43 continued to track after the antenna pre-limit was reached and DSS 63 was on point at antenna pre-limit prior to exit occultation. DSS 44 and DSS 62 provided S-band, closed-loop receiver occultation backup coverage and DSS 42 and DSS 61 performed dual-frequency, closed-loop receiver tracking of Voyager 2 to obtain independent measurements of the solar plasma for calibration of the occultation data. DSS 43 and DSS 63 tracked Voyager 1 with CONSCAN OFF and a fixed subreflector focus position so as to remove station-induced signal variations from the data. The occultation downlink was recorded on the medium-band, open-loop receiver system at DSS 63. Ionospheric data was obtained from the closed-loop system. The signal profile provided by the Project for the occultation did not prove to be as accurate during operations as did the one for Titan.

I. Ring Occultation

Immediately following the Saturn occultation exit was the ring occultation. The ring occultation lasted from the atmosphere of Saturn until exit from "F" ring (outermost visible ring) occultation. The duration of the ring occultation measurements was approximately 27 minutes.

The objectives of the ring occultation experiment were to:

(1) Map the optical depth of the rings at two radio wavelengths versus radial distance with high (less than 100 km) radial resolution.

(2) Determine the predominant particle size.

(3) Determine the number of particles per unit area and thus the mass of the rings.

The spacecraft high-gain antenna remained pointed at Earth for the duration of the ring occultation and the downlink configuration was a continuation of the Saturn occultation exit; X-band high power, S-band lower power, ranging channels OFF, telemetry drivers OFF, and TWNC ON. The primary ground events were supported by DSS 63 while DSS 62 provided S-band, closed-loop backup coverage and DSS 61 tracked Voyager 2 for the solar plasma calibration. Open-loop receiver recording was performed by DSS 63; however, a different configuration was used. Since polarization information was a primary data source, both RCP and LCP channels for S/X-band downlink were recorded. Also, these signals were recorded on the medium bandwidth system because large frequency dispersions were encountered. Closed-loop receiver system lock-up was not possible during the ring occultation.

J. Ring Scattering Experiment

A ring-scattering experiment was conducted during a period of approximately 100 minutes after completion of the ring occultation measurements. The spacecraft was maneuvered so as to track the center of the "A" ring with the HGA boresight. The objective of this experiment was to:

(1) Determine ring particle size and size dispersion in the decimeter to meter size range.

(2) Determine the vertical structure of the rings.

During the ring-tracking maneuver the HGA was 12 DEG off-Earth point and required precise tracking operation. After return to Earth point a mini-ASCAL was supported by the tracking station. All the ground events were supported by DSS 63 in the configuration as used for the ring occultation measurements.

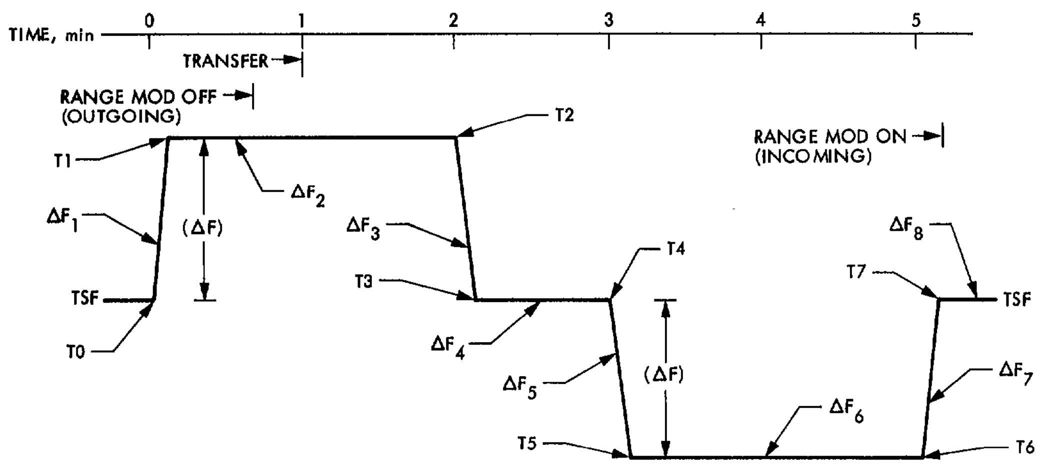
K. UVS Maneuver

On 22-23 November, an ultraviolet vertical scan maneuver was performed. The purpose of this maneuver was to align the long axis of the UVS instrument parallel to the ring plane. This was accomplished by performing yaw turns. The objective was to determine if a gas torus existed around Titan, and if so, to measure its extent.

During this maneuver the spacecraft was again off Earth point and downlink telemetry was lost. The maneuver took approximately 20 hours, during which a no data condition existed. DSS 14 supported the loss of data by tracking the signal with the SSI and supported the reacquisition of the downlink again making an early search with the SSI. The maneuver was successful and DSS 14 acquired the signal slightly after predicted time. DSS 61 and DSS 12 were backup to DSS 14 and acquired the downlink at the predicted time.

L. Post Encounter

Activities of 23-30 November settled into a routine of IRIS composition measurements, radio emission studies, plasma wave instability measurements, celestial mechanics studies, removal of residual measurements, coverage of Saturn's illuminated crescent, system scans, intensity of emission from Titan's orbit, and six-level system scan covering Titan's entire orbit. These data were received by the stations in either the real-time or playback modes during the normal scheduled tracking periods.



ΔF_1 = XA (OF TRANSFER) - TSF, COMPUTED TO ONE TENTH Hz

ALL TUNING RATES ARE 5 Hz/DC sec

T0 = TIME OF TRANSFER - 1 min

T2 = TIME OF TRANSFER + 1 min

T4 = TIME OF TRANSFER + 2 min

T6 = TIME OF TRANSFER + 4 min

PRA MUST NOT BE INTERRUPTED REGARDLESS OF TRANSMITTER OR RANGE MOD STATUS

DOPPLER SAMPLE INTERVAL = 10 sec

RECEIVER BANDWIDTHS SET 30 Hz-WIDE, NO TUNING AT TRANSFER REQUIRED

TRANSFERS TO OCCUR ON 35 min CENTERS

Fig. 1. An NSR transfer and its related events