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Telecommunications and Data Acquisition Systems Support for Voyager Missions to Jupiter and Saturn, 1972-1981

Prelaunch Through Saturn Encounter

M.R. Traxler
D.F. Beauchamp

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PREFACE

This is the first in a series of three volumes which document the activities of the Telecommunications and Data Acquisition (TDA) System for the Voyager Project. It carries on the tradition of providing this class of report for NASA's Deep Space Missions.

The TDA activities are initiated in the pre-project phase, sometimes known as the mission definition phase, wherein mission requirements are matched against then current network capabilities, and those new capabilities requisite for a meaningful mission are identified. This report covers the period from prelaunch through Saturn encounters by both Voyager spacecraft, ending in September 1981.

The Voyager missions presented new challenges in science data return which were met by arraying antennas to gain greater aperture for the Deep Space Network and by initiating the arraying technique with radio observatories.

A future document will cover activities from Saturn encounter through the Voyager 2 encounter period with the planet Uranus, which ends in March 1986. The final document will cover activities from July 1986 through the Neptune encounter period in September 1989.

N A Renzetti

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In preparing this report, the authors used published material from many sources within the Deep Space Network (DSN) and the Voyager Project engineering and operations organizations. The Network's monthly Progress Reports provided selected inputs describing DSN operations. Selected elements of the Radio Science Operations Plans were used for the Radio Science descriptions in Sections VII, VIII, X, and XI.

Special thanks are due Tom Taylor, Nick Fanelli, Hal Nance, Thorl Howe, Cal Edenburn, and Jack Nash who all contributed to the DSN operations descriptions. Bill Buckles provided valuable assistance in summarizing the Radio Science implementation and operations scenarios.

ABSTRACT

By 1983, the Deep Space Network had supported the Voyager Project for approximately nine years, during which time implementation, testing, and operational support had been provided. Four years of this time involved testing prior to launch; the final five years included Network operations support and additional Network implementation. Intensive and critical support intervals included launch in 1977 and four planetary encounters in 1979, 1980, and 1981. This document is the first in a series of three documents and summarizes the Telecommunications and Data Acquisition support for the Voyager Missions to Jupiter and Saturn. Future documents will cover activities from Saturn encounter through encounter with Uranus in 1986 and Neptune in 1989.

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SECTION I

INTRODUCTION

A. SCOPE

This report documents the engineering and operation activities of the Deep Space Network (DSN) in support of the Voyager mission to Jupiter and Saturn. It summarizes major planning, implementation, testing, operational support, problems, and highlights.

The report documents the support to both Voyager spacecraft. It is divided into eleven sections with emphasis placed on the implementation and support provided for the two Jupiter and Saturn encounters in Sections VII, VIII, X, and XI.

B. TIMELINE

A timetable of key Voyager events is provided in Table 1-1. The Voyager 2 spacecraft was launched on August 20, 1977. The Voyager 1 spacecraft was launched 16 days later on September 5, 1977.

The primary mission of the Voyager spacecraft was to make various types of scientific measurements of Jupiter and Saturn. The Voyager 1 spacecraft closest approach to Jupiter occurred on March 5, 1979. Voyager 2 arrived at Jupiter July 9, 1979. Both spacecraft were targeted at Jupiter to use the planet's gravity to help deflect the spacecraft on a trajectory to Saturn. Voyager 1 arrived at Saturn on November 13, 1980. The Voyager 2 closest approach to Saturn occurred about nine months later, on August 25, 1981.

The Voyager spacecraft are presently executing a new mission plan defined in the Voyager Uranus Interstellar Mission (VUIM) Plan. This plan, and the DSN support of it, started on October 1, 1982. This report does not address any of the aspects of the VUIM plan except where the targeting for Uranus is discussed as part of the Voyager 2 Saturn encounter plan.

Table 1-1. Voyager Chronological Schedule

Date	Event
1973	Program Authorization Document signed
1972-1977	DSN prelaunch planning and implementation
August 20, 1977	Voyager 2 launch
September 5, 1977	Voyager 1 launch
September 1977 - January 1979	Voyager 1 cruise phase to Jupiter encounter

Table 1-1. Voyager Chronological Schedule (continued)

Date	Event
January 4, 1979 - April 9, 1979	Voyager 1 observatory, encounter, and post-encounter phases at Jupiter
March 5, 1979	Voyager 1 closest approach to Jupiter
August 1977 - April 1979	Voyager 2 cruise phase to Jupiter encounter
April 24, 1979 - August 28, 1979	Voyager 2 observatory, encounter, and post-encounter phases at Jupiter
July 9, 1979	Voyager 2 closest approach to Jupiter
April 1979 - October 1980	Voyager 1 cruise Jupiter to Saturn
August 23, 1980 - December 19, 1980	Voyager 1 observatory, encounter, and post-encounter phases at Saturn
November 13, 1980	Voyager 1 closest approach at Saturn
December 1980 - September 1981	Voyager 1 cruise through solar system
July 1979 - June 1981	Voyager 2 cruise to Saturn
June 5, 1981 - September 28, 1981	Voyager 2 observatory, encounter, and post-encounter phases at Saturn
August 25, 1981	Voyager 2 closest approach to Saturn

C. SUMMARY OVERVIEW, HIGHLIGHTS AND PERCEPTIONS

This document covers a span of approximately nine years during which implementation, testing, and operational support were provided to Voyager. The first four years before launch involved implementation and testing. The final five years included DSN operations support and additional Voyager implementation. The DSN support period included about one year of intensive operational support activities. These intensive and critical support intervals included launch in 1977 and the four planetary encounters in 1979, 1980, and 1981.

In addition, new Voyager capabilities in the form of new implementations specifically for an upcoming encounter were completed before each encounter. During the prelaunch period of time and before each of the encounters, DSN implementation always seemed to be more than could be readily managed in the time available. There were several reasons for this. Often funds were not available to start the implementation as early as desired. Also much of the implementation was difficult state-of-the-art and required long testing periods. In any event, through innovative engineering and dedication to the task, the implementation was completed on time.

The right tools were available for the DSN engineering organization to succeed, in that a good research and development program for many of the state-of-the-art capabilities set the stage for engineering production of several of the needed capabilities. Among these were the new X-band low noise masers, baseband combining of telemetry signal, and larger aperture station antennas with X-band capability. Many of these new capabilities were made possible by forward thinking personnel at both JPL and Headquarters. This allowed the many engineering challenges that were presented by the Voyager mission to be met. One of the biggest implementation and operations challenges for the Voyager mission was that associated with uplink tuning with the Voyager 2 spacecraft necessitated by the failure of a spacecraft receiver capacitor on April 5, 1978.

The overall operational support for the Voyager Jupiter and Saturn encounters was excellent. There were several operational challenges for these encounters. Encounters themselves were of long duration, approximately three months for each of the encounters. During these encounters much critical data was required, and to ensure obtaining this data, many special procedures were used. These special procedures included backup data strings for telementry and command, backup recordings, and modified configuration freezes. The necessity to support another prime mission, Pioneer Venus, during the Voyager 2 Jupiter encounter further complicated operations.

DSN operations provided outstanding support for the Voyager 1 and 2 spacecraft during the Jupiter encounters periods with a total of approximately 44,500 images obtained. The Voyager 1 and 2 Saturn encounters were also supported in an excellent manner by the DSN. Approximately 29,500 images were obtained during these two encounters. The DSN obtaining 99.8 percent of all pictures attempted. This percentage included losses of all types including loss of signal due to weather.

Implementation lessons learned were: (1) start funding and implementation early; (2) define the task in detail; and (3) develop a realistic testing schedule with some margin for retesting.

The reasons for exceptional DSN success were manyfold, but can be summarized as follows: (1) good advanced engineering and technology development organization; (2) timely implementation of Voyager specific capabilities by dedicated personnel; (3) dedicated and inspired operations organization; (4) fortunate circumstances. The dedicated and inspired operations organization was probably the largest contributor to the exceptional DSN success. All organizations at JPL seemed to be spurred on by the huge public interest in the spectacular Jupiter and Saturn encounters.

The DSN is presently looking forward to the new challenges that will be forthcoming in the continued journey of Voyager 2 to the planet Uranus.

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SECTION II

PRELAUNCH PLANNING AND IMPLEMENTATION

A. INTRODUCTION

During the four years preceding the Voyager launches, the Network was configured to support Viking, Helios, Pioneer and other activities with emphasis placed on the Viking critical support. A Voyager Support Instrumentation Requirements Document was developed in 1975 by the Project, in concert with the Tracking and Data Systems Manager, describing capabilities and support needed for Voyager.

These requirements were factored into the long range planning to integrate new multimission and Voyager implementation. This implementation was developed and a major portion of it executed during the 1975 through 1977 time period.

There was one major implementation effort specifically for Voyager. This implementation effort was agreed to in principle in 1975 between the project and the DSN, and its primary purpose was to provide about 1.9 dB equivalent X-band telemetry signal increase at all 64-meter locations. This implementation included X-band radio frequency improvements to the DSN 64-meter antenna front end area and baseband combining of the telemetry signal.

Most of the DSN implementation which preceded the Voyager launches related to multimission improvements such as the Mark III 1977 Data Subsystem Implementation Project, which was not completed at all sites before launch. This was worked around by DSN operations and is described in later parts of this section.

B. DSN PREPARATIONS FOR LAUNCH AND ENCOUNTER

The Voyager mission requirements defined in the Support Instrumentation Requirements Document were developed in 1975 and approved in 1976 by NASA Headquarters. The Tracking and Data Systems Manager responded to these requirements in 1976 with a NASA Support Plan and a Preparations Plan for Voyager.

The NASA Support Plan (NSP) committed specific DSN capabilities to the Voyager project for use in mission planning. The Preparations Plan documented the DSN implementation, capabilities, and configurations needed to support the Voyager mission. The DSN implementation organization used the NASA Support Plan and Preparation Plan as guides to the multimission and Voyager specific implementation. The DSN operations organization used these plans as the basis for the Network Operations Plan for Voyager, which provided detailed operational instructions to all elements of the DSN.

The latter part of 1976 and all of 1977 were hectic months of implementation for the DSN. Significant new capabilities were implemented consistent with Voyager launch and critical support activities as part of the DSN Mark III 1977 Data Subsystem Implementation Project. Consequently, network prelaunch test and training activities were extensive.

After the Helios 2 launch in 1976, new Antenna Pointing Subsystem (APS) software and Planetary Ranging Assembly (PRA) software were implemented, tracking prediction software was extensively modified, the Metric Data Assembly (MDA) and its associated software were newly implemented, and the Network Support Controller (NSC) was brought into use. During the extensive prelaunch testing of these subsystems, several flaws were discovered. All of the above-mentioned elements underwent some degree of modification during the last few months before launch. More detail on these capabilities is provided in sections II-D and II-E.

The implementation to obtain the equivalent of 1.9 dB of X-band telemetry signal at a complex was not needed at launch. This additional equivalent telemetry signal gain was primarily to improve the X-band Voyager signal margin and allow higher spacecraft data rates at Saturn. These improvements are described in more detail in Sections VII, VIII, and X of this document. The planning and budgeting of these improvements was started in 1975 with Deep Space Station (DSS) 14 partially implemented before launch. The additional improvements at DSS 14 and the overseas 64-meter stations were completed before the Voyager 1 Saturn encounter. See section X-A for more details.

C. VOYAGER END-TO-END DATA FLOW CONFIGURATION

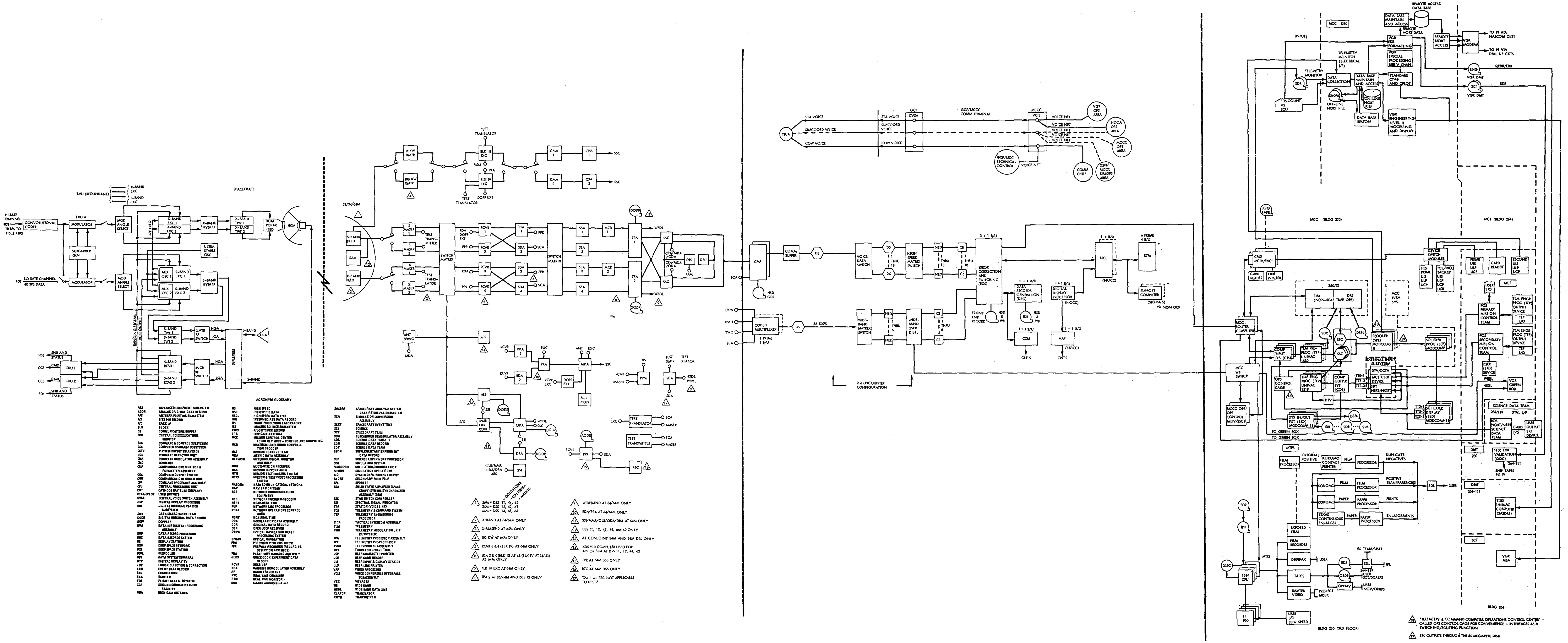
The Voyager end-to-end data flow configuration is shown in Figure 2-1. The diagram reflects those data flow capabilities and associated hardware configurations required to meet the Voyager Project mission objectives. Both the initial configuration and changes which occurred during the mission are illustrated in the diagram. The overall data flow is presented in this report to provide the reader a better understanding of the magnitude of the DSN effort required to support the Voyager Mission. Although the drawing presented does not provide the detailed assembly level information discussed in this report, the level of detail presented does allow the reader to identify where the subsystems discussed fit into the overall system.

D. OPERATIONAL IMPACTS OF NEW DEVELOPMENTS AND MODIFICATIONS

In March of 1977, the DSN tracking prediction system was completely changed. The previous system relied entirely on topocentric trajectory data in the form of a polynomial coefficient tape (PCT) generated by the project navigation team. This PCT was then evaluated by the PREDIK software to reproduce tracking predictions.

The new (and currently used) system requires as input a probe ephemeris tape (PET) containing the probe trajectory in terms of a central body. The PET then becomes the input to the Fast Phi-Factor Generator Program (FPGP), which translates these data to topocentric observables and generates the PCT input to PREDIK.

In the course of generating the many predicts sets required to characterize the launch trajectories, it was found that the FPGP could not quickly or accurately produce launch phase predictions. These problems obviously caused concern that FPGP could not be used at all during the launch phase of Voyager. To improve the running time of FPGP, extensive changes were made to the program files. These changes resulted in the elimination of two



ACRONYM GLOSSARY

AES	ADVANCED EQUIPMENT SUBSYSTEM
AODR	ANALOG ORIGINAL DATA RECORD
APS	ANTENNA POINTING SUBSYSTEM
B/S	BITS PER SECOND
B/U	BACK-UP
BLK	BLOCK
CB	COMMUNICATIONS BUFFER
CCM	CENTRAL COMMUNICATIONS MONITOR
CCS	COMMAND & CONTROL SUBSYSTEM
CCS	COMPUTER COMMAND SUBSYSTEM
CCTV	CLOSED CIRCUIT TELEVISION
CDU	COMMAND DETECTOR UNIT
CMA	COMMAND MODULATOR ASSEMBLY
CMD	COMMAND
CMF	COMMUNICATIONS MONITOR & FORMATTER ASSEMBLY
COS	COMPUTER OUTPUT SYSTEM
COW	COMMUNICATIONS ORDER WIRE
CPA	COMMAND PROCESSOR ASSEMBLY
CPU	CENTRAL PROCESSING UNIT
CRT	CATHODE RAY TUBE (DISPLAY)
CTAB/CPLOT	USER OUTPUTS
CVSA	CENTRAL VOICE SWITCH ASSEMBLY
DDP	DIGITAL DISPLAY PROCESSOR
DIS	DIGITAL INSTRUMENTATION SUBSYSTEM
DMT	DATA MANAGEMENT TEAM
DODR	DIGITAL ORIGINAL DATA RECORD
DOPP	DOPPLER
DRA	DATA (OR DIGITAL) RECORDING ASSEMBLY
DRP	DATA RECORD PROCESSOR
DRS	DATA RECORDS SYSTEM
DS	DISPLAY STATION
DSN	DEEP SPACE NETWORK
DSS	DEEP SPACE STATION
DSPL	DESPOOLER
DST	DATA SYSTEM TERMINAL
DTV	DIGITAL DISPLAY TV
EDC	ERROR DETECTION & CORRECTION
EDR	EVENT DATA RECORD
ENG	ENGINEERING
EXC	EXCITER
FDS	FLIGHT DATA SUBSYSTEM
GCF	GROUND COMMUNICATIONS FACILITY
HGA	HIGH GAIN ANTENNA
HS	HIGH SPEED
HSD	HIGH SPEED DATA
HSDL	HIGH SPEED DATA LINE
IDR	INTERMEDIATE DATA RECORD
IPL	IMAGE PROCESSING LABORATORY
ISS	IMAGING SCIENCE SUBSYSTEM
KBPS	KILOBITS PER SECOND
LGA	LOW GAIN ANTENNA
MCC	MISSION CONTROL CENTER FORMERLY MCCC – CONTROL AND COMPUTING
MCD	MAXIMUM-LIKELIHOOD CONVOLUTION DECODER
MCT	MISSION CONTROL TEAM
MDA	METRIC DATA ASSEMBLY
MET-MON	METEOROLOGICAL MONITOR ASSEMBLY
MMR	MULTI-MISSION RECEIVER
MSA	MISSION SUPPORT AREA
MTIS	MISSION TEST IMAGING SYSTEM
MTPS	MISSION & TEST PHOTOPROCESSING SYSTEM
NASCOM	NASA COMMUNICATIONS NETWORK
NAV	NAVIGATION TEAM
NCE	NETWORK COMMUNICATIONS EQUIPMENT
NED	NETWORK ENCODER-DECODER
NERT	NEAR-REAL TIME
NLP	NETWORK LOG PROCESSOR
NOCA	NETWORK OPERATIONS CONTROL AREA
NORT	NON-REAL TIME
ODA	OCCULTATION DATA ASSEMBLY
ODR	ORIGINAL DATA RECORD
OLR	OPEN-LOOP RECEIVER
ONIPS	OPTICAL NAVIGATION IMAGE PROCESSING SYSTEM
OPNAV	OPTICAL NAVIGATION
PPM	PRECISION POWER MONITOR
PPR	PRE/POST RECORDER (RECORDING DETECTION ASSEMBLY)
PRA	PLANETARY RANGING ASSEMBLY
QEDR	QUICK-LOOK EXPERIMENT DATA RECORD
RCVR	RECEIVER
RDA	RANGING DEMODULATOR ASSEMBLY
RF	RADIO FREQUENCY
RTC	REAL TIME COMBINER
RTM	REAL TIME MONITOR
SAA	S-BAND ACQUISITION AID
SASORS	SPACECRAFT ANALYSIS SYSTEM DATA RETRIEVAL SUBSYSTEM
SCA	SIMULATION CONVERSION ASSEMBLY
SCET	SPACECRAFT EVENT TIME
SCI	SCIENCE
SCT	SPACECRAFT TEAM
SDA	SUBCARRIER DEMODULATOR ASSEMBLY
SDL	SCIENCE DATA LIBRARY
SDR	SCIENCE DATA RECORD
SDT	SCIENCE DATA TEAM
SEDR	SUPPLEMENTARY EXPERIMENT DATA RECORD
SEP	SCIENCE EXPERIMENT PROCESSOR
SIM	SIMULATION SYSTEM
SIMCOORD	SIMULATION/COORDINATION
SIMOPS	SIMULATION OPERATIONS
SIO	SYSTEM INPUT/OUTPUT DEVICE
SNORT	SECONDARY NORT FILE
SPL	SPOOLER
SSA	SOLID STATE AMPLIFIER (SPACECRAFT) SYMBOL SYNCHRONIZER ASSEMBLY (DSN)
SSC	STAR SWITCH CONTROLLER
SSI	SPECTRAL SIGNAL INDICATOR
STA	STATION (VOICE LINE)
TCS	TELEMETRY & COMMAND SYSTEM
TEP	TELEMETRY ENGINEERING PROCESSOR
TICA	TACTICAL INTERCOM ASSEMBLY
TLM	TELEMETRY
TMU	TELEMETRY MODULATION UNIT (SUBSYSTEM)
TPA	TELEMETRY PROCESSOR ASSEMBLY
TPP	TELEMETRY PRE-PROCESSOR
TVSA	TELEVISION SUBASSEMBLY
TWT	TRAVELLING WAVE TUBE
UCP	USER CHARACTER PRINTER
UCR	USER CARD READER
UIS	USER INPUT & DISPLAY STATION
ULP	USER LINE PRINTER
VAP	VIDEO PROCESSOR
VCIS	VOICE CONFERENCE INTERFACE SUBASSEMBLY
VGR	VOYAGER
WB	WIDE-BAND
WBDL	WIDE-BAND DATA LINE
XLATOR	TRANSLATOR
XMTR	TRANSMITTER

GOLDSTONE CANBERRA MADRID

1. 26M = DSS 11, 44, 62
34M = DSS 12, 42, 61
64M = DSS 14, 43, 63
2. X-BAND AT 34/64M ONLY
3. X-MASER 2 AT 64M ONLY
4. 100 KW AT 64M ONLY
5. RCVR 3 & 4 (BLK IV) AT 64M ONLY
6. SDA 3 & 4 (BLK III AT 63)(BLK IV AT 14/43) AT 64M ONLY
7. BLK IV EXC AT 64M ONLY
8. TPA 2 AT 26/64M AND DSS 12 ONLY
9. WIDEBAND AT 34/64M ONLY
10. RDA/PRA AT 34/64M ONLY
11. SSI/MMR/OLR/ODA/DRA AT 64M ONLY
12. DSS 11, 12, 42, 44, and 62 ONLY
13. AT CONJOINT 34M AND 64M DSS ONLY
14. XDS 910 COMPUTER USED FOR APS OR SCA AT DSS 11, 12, 44, 62
15. PPR AT 64M DSS ONLY
16. RTC AT 64M DSS ONLY
17. TPA 1 WB REC NOT APPLICABLE TO DSS12
18. "TELEMETRY & COMMAND COMPUTER OPERATIONS CONTROL CENTER" - CALLED OPS CONTROL CAGE FOR CONVENIENCE - INTERFACES AS A SWITCHING/ROUTING FUNCTION
19. SPL OUTPUTS THROUGH THE 50 MEGABYTE DISK

Figure 2-1. Voyager End-to-End System Data Flow

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tapes and much operator intervention. This streamlining allowed the running time to be reduced significantly.

It was also discovered that the FPGP tended to overfit when the observables were undergoing a high rate of change. To correct this situation, the FPGP was modified to allow user control of the minimum span duration, thereby diminishing the tendency toward overfitting.

In later testing (within three weeks of launch), it was found that the time from launch (TFL) option did not function correctly. While copies of the predicts produced at the Jet Propulsion Laboratory (JPL) had the proper time field, those received at the stations did not. Since this was an important launch phase predicts option, the cause of the problem (one line of the program had been inadvertently omitted) was quickly isolated and corrected.

The Network Support Controller (NSC) was the Sigma 5 computer used to generate and transmit tracking and telemetry predictions as well as other products, such as the sequence of events and schedule. During prelaunch testing, it was found that the NSC software used in the construction of transmission files would not accept the Voyager spacecraft identifiers. It was also discovered during the testing cycle that the Metric Data Assembly (MDA) would not permit reception of a single pass of predictions. During the launch phase, predictions were generated on a single-pass basis. Both programs were quickly modified to correct these anomalies.

Thus, after a less-than-encouraging start, the prediction system was finally ready for launch support with less than three weeks to spare.

With the implementation of the APS II software in early 1976, the format of the antenna drive tape was changed, thereby nullifying the drive tape verification software. This left only a checksum computation for verification of the drive tape. It was believed that this method of verification was inadequate for support during this critical phase. The original APS drive tape verification program was therefore quickly modified and brought into operational use just weeks before the Voyager 2 launch.

In late May, analysis of ranging data from DSS 12 revealed a one-second error in the range acquisition time (T_0) as reported by the MDS version of the Planetary Ranging Assembly (PRA) software. Like the other previously discussed problems, this one was quickly corrected and the PRA was made ready for launch support.

E. OPERATIONS PLANNING

Prelaunch operations planning included the development of an Antenna Pointing Subsystem (APS) drive tape generation strategy to assure that the best available drive tape was provided to the initial acquisition station. The strategy included the generation of multiple drive tapes based on the best available prelaunch data and culminated in the generation of a postlaunch tape based on the actual liftoff data.

The angle drive strategy for Voyager was essentially the same strategy successfully used during previous launches and was based upon the following considerations:

(1) It was desired that the uplink be acquired shortly after rise.

(2) Usage of a drive tape was required during the one-way to two-way transition.

(3) Acquisition of early (near-earth) autotrack data was desired.

(4) It was desired to lock the receiver coupled to the S-band cassegrain antenna as well as the receiver coupled to the S-band Acquisition Antenna (SAA) prior to initiation of the uplink sweep.

It was planned that at least four and possibly five drive tapes would be generated to assure the station of the best available drive tape. The antenna drive strategy then became:

(1) At launch minus seven days (or L-24 hours, if the launch date slipped), open-, mid-, and close-window drive tapes were to be generated. These tapes were in TFL format and were to be used as backups for drive tapes produced during the final countdown. To use these tapes, a time offset (Δt) equal to the actual liftoff time would be entered into the APS. The tape to be used would be specified by the Tracking Network Operations Analyst (NOA).

(2) At L-105 minutes, a new drive tape with times in Greenwich Mean Time (GMT) format would be generated. It had been determined previously that (based upon an analysis of angle rates) the S-band Cassegrain Monopulse (SCM) antenna beam width would tolerate an error of up to three seconds in liftoff time before it would become extremely difficult to lock the receivers. The L-105 minute predicts would then be prime if launch was within three seconds of the expected time.

(3) At L-4 minutes, a contingency predicts set based upon a liftoff-plus-three-second trajectory would be generated. If liftoff was more than three seconds late, these predicts would be transmitted to the station for use in punching a drive tape.

(4) Finally, if none of the previously mentioned drive tapes were adequate, a prediction set based on the actual liftoff time would be generated as soon as that time became known. A drive tape based on these predictions would become prime.

Following the uplink acquisition, and as early as practicable, the antenna drive mode would be changed to autotrack. This switch would be accomplished in three steps: (1) the signal on the SAA receiver would be peaked, using offsets to the latest available drive tape; (2) autotrack would then be accomplished on the SAA; and (3) autotrack would be accomplished on the SCM.

The Voyager initial uplink acquisition had been designed with the following criteria in mind:

(1) The uplink should be acquired at the earliest practicable time, based on station capabilities and spacecraft trajectory constraints.

(2) The uplink acquisition sweep should span a frequency range and be at a rate that best guarantees acquisition on the first sweep.

(3) The uplink acquisition should be complete in time to have all stations (particularly DSS 14) ready to receive the critical 7.2 kb/s telemetry data.

The following uncertainty information pertaining to the uplink was made available by the Voyager project:

3σ trajectory	192 Hz (S-band)
3σ measurement	1000 Hz (S-band)
3σ receiver "random walk"	2000 Hz (S-band)
3σ spacecraft Temperature	1500 Hz (S-band)

Combining the above, one arrives at a total 3σ uncertainty of 2700 Hz (S-band) or 28 Hz (VCO).

This uncertainty was extremely small with respect to uncertainties for previous missions (for instance 3σ for Viking was 5300 Hz); therefore, to be extremely conservative (and hence allow for any sort of abnormal launch vehicle or spacecraft performance) and since there was no real impact on tuning duration, the previously described 3σ uncertainty was more than tripled, resulting in a sweep of approximately XA $\pm$9600 Hz (S-band) or XA $\pm$100 Hz voltage-controlled oscillator (VCO).

The Voyager spacecraft receiver tuning rates are bounded by 60 Hz/s < tuning rate < 1000 Hz/s (S-band) or 0.6 Hz/s < tuning rate < 10 Hz/s (VCO) under the strong signal (-100 decibels referred to 1 milliwatt, dBm) conditions that were to be encountered during the initial pass. For the initial acquisition, a sweep rate of 3 Hz/s (VCO) or 288 Hz/s (S-band) was selected because:

(1) The rate was well above the push limit of the receiver and thus would result in a successful acquisition.

(2) Should it become necessary to manually tune the exciter, it was believed that the station could not accurately tune at a higher rate than the chosen rate.

(3) A rate of 288 Hz/s (S-band) would result in an effective (doppler rates considered) tuning rate of approximately 238 Hz/s at the spacecraft receiver. This rate was very nearly the geometric mean of the upper and lower sweep rate limits (245 Hz/s.)

The sweep was to start at liftoff plus 78 minutes, approximately five minutes after the spacecraft would have risen. This allowed sufficient time for the necessary sideband or sidelobe searches before starting the uplink acquisition.

Finally, the sweep was to consist of a single upleg in the direction of the change of XA, with the ending frequency becoming the track synthesis frequency (TSF) for the remainder of the pass. This was advantageous in that no additional tuning to reduce static phase error (SPE) would be required during the remainder of the pass.

Incorporating the preceding information, the general uplink acquisition procedure was:

(1) Transmitter connnected to the S-band Acquisition Aid Antenna (SAA) and set to radiate at 10 kW.

(2) Transmitter on at start of uplink sweep minus 20 seconds.

(3) Radio metric data to be flagged two-way at start of the sweep minus 10 seconds. (This would enable the Network Operations Control Team (NOCT) to know when, and if, two-way lock was achieved and whether lock was on the main carrier or a sideband.)

(4) Sweep to start at L+78 minutes or approximately five minutes after spacecraft rise.

(5) Sweep to cover at least XA ±100 Hz (VCO) at a rate of 3 Hz/s (VCO).

(6) Sweep duration to be approximately 80 seconds.

If the first sweep failed, a contingency sweep encompassing a region 50 percent larger (XA ±150 Hz (VCO)) than the original sweep would be performed, starting 2 minutes and 30 seconds after completion of the first sweep. The contingency sweep would consist of a downleg and an upleg followed by a sweep back to TSF, executed continuously with no pauses between legs. (Of course, if two-way was achieved any time during the contingency sweep, the station was to stop tuning, lock the receivers, and then tune directly to TSF.) The tuning instructions for both sweeps were to be provided to DSS 12, via a sweep message, well before liftoff.

F. DSN OPERATIONAL TESTING AND TRAINING

1. Operational Verification Testing

For prelaunch, launch, and early-mission support, the DSN commitment for readiness of Network stations was as follows:

(1) The Compatibility Test Area (CTA 21) for spacecraft-network compatibility tests and DSN development.

(2) The Spaceflight Tracking and Data Network (STDN) station at Merritt Island (MIL 71) for spacecraft-network compatibility verifications and near-earth launch support.

(3) One 26-meter subnet of three stations: DSS 12 (California), DSS 44 (Australia), and DSS 62 (Spain) for cruise support.

(4) One 64-meter station, DSS 14, for periodic high-rate data acquisition and S-X band radio metric data generation. Most of the Voyager compatibilities required were provided through the DSN Mark III '77 Data Subsystem (MDS) Implementation Project.

Mission-dependent network test and training activities following the MDS implementation were key factors in achieving DSN operational readiness prior to Voyager launch.

The training problem associated with the MDS conversions was twofold. First, the DSN was supplied with new hardware and software; and second, Voyager procedures and configurations were new. The first problem was to familiarize DSN personnel with the new MDS equipment and associated software procedures.

DSN testing for Voyager centered on the prime 26-meter DSN stations to be used for launch and cruise (DSS 12, DSS 44, and DSS 62). DSS 12 was the first of these to receive the MDS update Operational Verification Tests (OVTs), which were started immediately after all System Performance Tests (SPTs) were completed. This being the first Goldstone station to be converted to MDS, it was used as the testbed for all Complex MDS training. The objectives of the Voyager mission-dependent training were to:

(1) Familiarize the station and NOCT personnel with the Mark III Data System pertaining to the support of the Voyager mission.

(2) Provide experience with the MDS equipment and Voyager configurations and operational procedures.

(3) Ensure that all network operational personnel were adequately trained to support all Voyager mission activities.

Problems experienced at DSS 12 were numerous. Growing pains of new hardware, new software, and operational personnel unfamiliarity with both, plagued the first few Operational Verification Tests. Approximately 30 percent of the OVTs performed at Station 12 produced more problems than training benefit. (A total of 10 OVTs were run with DSS 12.) Half of these tests were completed before results of the training could be seen. This was not altogether unexpected, and the problem experienced with Station 12 led to identifying, documenting, and eventually correcting hardware configurations, software, and procedures. Further DSN tests with CTA 21 and MIL 71 also contributed to resolving these problems.

By the time DSS 62 DSN OVTs were begun, new command, telemetry, and Communications Monitor and Formatter Assembly (CMF) software versions were at the station. Test results began to improve. All OVTs performed with DSS 62 were successful. Minor problems which did occur were usually corrected before the next test.

Software reliability and operational procedures continued to improve by the time DSS 44 testing began. Only one of nine OVTs at DSS 44 was unsuccessful, and this was due to equipment outage. With the highly successful completion of DSS 44 testing, the 26-meter subnet required for Voyager launch phase and early cruise was ready for support.

Because of the Voyager launch trajectory, DSS 12 was selected as the initial acquisition station. (This was the first time a Goldstone station was used for initial acquisition.) Special initial acquisition OVTs were run to familiarize station personnel with initial acquisition procedures. These tests went very smoothly. Several tests using a geodetic earth-orbiting satellite (GEOS) (fast-moving) were conducted by DSS 12 to practice initial acquisition procedures and acquire much needed experience.

As the MDS schedule shows, there was little time to achieve DSS 14 operational readiness prior to launch. However, Viking support requirements dictated the downtime schedule, and Voyager had to assume the limited test and training risks.

The first test with DSS 14 was on 27 June 1977. The test failed due to station air conditioning problems and a Network Data Processing Area (NDPA) software failure. Approximately one-half of the DSS 14 OVTs experienced major difficulties which were primarily hardware-related.

Station Configuration Verification Tests (CVTs) were conducted with MIL 71, DSSs 11, 12, 44, and 62 on August 17, 18, and 19, 1977. With these CVTs, the stations were placed under configuration control for Voyager 2 launch. (Table 2-1 provides a summary of all prelaunch tests that were conducted.)

Voyager 2 launch occurred on 20 August 1977. Between Voyager 2 launch and Voyager 1 launch on September 5, the recertification of DSS 14 was ensured by performing a Configuration Verification Test (CVT) on 4 September 1977. DSSs 12, 44, and 62 had been tracking the Voyager 2 spacecraft daily, so their configuration was still validated. The second CVT at DSS 14 was very successful, and the station was placed under configuration control for the Voyager 1 launch.

The first conjoint deep space station (DSS 42/43) was taken down in July 1977 for the Mark III Data System conversion. The DSS 42/43 combined system test was conducted on 24 September 1977, signaling the end of the System Performance Tests (SPTs) and the start of the two-month DSN testing phase.

Being a conjoint station, DSS 42/43 presented further problems in that one CMF is used to transmit data from both stations simultaneously. Although it was a minor change to the basic 64/26-m MDS configuration, the impact to operations and what to expect in the way of interaction was not fully understood.

At the request of DSS 42/43 management, a new testing technique was used. The first day was scheduled for on-site training, followed by Viking OVT (16 hours per day), completing the first week. Viking was selected because it was a project the operational personnel were familiar with, rather than starting with a new project (like Voyager or Pioneer Venus).

Table 2-1. Summary of Prelaunch Voyager Test Activities, 15 Nov. 1976 Through 19 Aug. 1977

Test	CTA 21	MIL 71	DSS 11[a]	DSS 12	DSS 14	DSS 44	DSS 62
DFT	0	1	0	2	1	1	1
OVT	0	9	0	10	7	9	7
PDT	0	1	0	1	1	1	1
CVT	0	1	1	1	1	1	1
MEIVT/DEIVT	9	3	0	2	3	1	1
GDS test	7	2	0	5	1	1	1
Initial acquisition	0	0	0	5	0	0	0
Special tests	6	15	3	4	10	0	0
S/C monitor	0	6	0	0	0	0	0
MOS test	0	4	0	4	7	1	2
ORT	0	2	2	2	2	1	1

[a] Non-MDS Station

DFT = Data Flow Test
OVT = Operational Verification Test
PDT = Performance Demonstration Test
CVT = Configuration Verification Test
MEIVT = MCCC Engineering Interface Verification Test
DEIVT = Department of Science and Environment (DSE) Interface Verification Test
GDS = Ground Data System
S/C = Spacecraft
MOS = Mission Operations System
ORT = Operational Readiness Test

The Spanish Complex at DSS 61/63 was converted to the MDS system during the period 15 October through December 1977. DSN OVT started in early January 1978. Again, a minimum of two OVTs were conducted with each operational crew. Simulation Conversion Assembly (SCA) and communication equipment problems plagued the first half of testing. After these problems were cleared, the remaining tests proceeded smoothly. The station became operational on 31 January 1978.

Deep Space Station 11, the last of the network to be converted, was taken down on schedule (mid-January).

2. Mission Operations System Test Support

Problems with DSS 14 continued into the first Mission Operations System (MOS) tests. As the MOS and special testing continued, the problems at DSS 14 decreased, but never diminished altogether. Because DSS 14 would play an important role on the initial pass over Goldstone, special tests were designed to further test the equipment and provide additional training to station personnel. By the first Operational Readiness Test (ORT), DSS 14's performance had vastly improved. The ORT was a success with only minor problems. Three Science and Mission Plans Leaving Earth Region (SAMPLER) OVTs were conducted with DSS 14, which provided additional training. SAMPLER, a special earth sequence, was cancelled by the project before launch.

In the last three weeks before the launch of Voyager 2, several MOS tests were conducted with the spacecraft (at Cape Canaveral) providing the telemetry data. Although several stations were involved in these tests, MIL 71 was engaged in all of them. For the most part, MIL 71's performance was outstanding.

ORT number 2 was conducted on 14 and 15 August 1977. Stations participating in this test were MIL 71 and DSSs 11, 12, and 14. Both DSS 12 and 14 experienced some equipment and operations anomalies; however, it was felt that they could be corrected before launch.

SECTION III

COUNTDOWN AND LAUNCH

A. GENERAL

Many activities were required to come together to allow the successful countdown and launch of the Voyager spacecraft. Some of the most important of these were the readiness of the launch vehicle, spacecraft radio frequency compatibility and prelaunch test program, near-earth phase network support readiness, and DSN support readiness.

The launch vehicle prelaunch preparations on the Titan III-C/Centaur D-IT and its integration with the Voyager spacecraft went well, with no major launch vehicle problems. The spacecraft testing and integration was very hectic for both Voyager spacecrafts, with problems occurring the final weeks before launch.

The near-earth phase network had all resources and capabilities ready for the two Voyager launches and was not a consideration in any launch slips. The DSN was in the process of a major system implementation during the launch time period and therefore developed a plan to support the Voyager launches with selected stations in the old configuration at selected sites and the new configuration for most of the DSN stations.

The Voyager launch vehicle consisted of a Titan III-C/Centaur D-1T/ propulsion module configuration. This configuration delivered the spacecraft into a transfer orbit to Jupiter.

The Titan and Centaur were standard launch vehicle stages, and the propulsion module was a solid stage integrated as part of the Voyager spacecraft, with attitude control being provided by the Voyager control system.

The spacecraft trajectory used Jupiter gravity assist to aid in redirecting the spacecraft toward Saturn.

The Titan stages and the Centaur first engine burn placed the Voyager vehicle in a circular orbit of approximately 90 nautical miles. The spacecraft then coasted for approximately 42 minutes, and the Centaur second burn occurred above the Indian Ocean west of Australia. The Centaur second burn was approximately 5.5 minutes on the first launch and 5.8 minutes during the second launch.

The propulsion module burn occurred 185 seconds after the Centaur second main engine cutoff and lasted 45 seconds.

The real challenge during the launch activities was to launch two spacecraft from one Titan Centaur pad within a fixed launch window of 31 days. This was further complicated by the fact that there was a minimum ten-day turnaround to prepare the pad for a second launch. The initial planned launch dates were August 20 for Voyager 2 (Mission A) and September 1 for Voyager 1 (Mission B).

B. VOYAGER 2 (MISSION A) LAUNCH

Voyager 2 was launched on August 20, 1977, at 10:29 a.m., on the opening day of its launch window, with less than a five-minute delay from the earliest planned launch time. This launch was accomplished by herculean efforts in the last three weeks before launch. Failures in the attitude and articulation control subsystem (AACS) and a flight data subsystem computer prevented the use of the Voyager 2 spacecraft originally planned for launch. Instead, the flight-ready spare spacecraft was substituted and intensive testing accomplished to allow the launch on August 20. During the final preparation, the low-energy charge particle instrument failed and had to be replaced. The launch was delayed for 5 minutes because of a faulty valve indication in the launch vehicle.

The Titan-Centaur performance was nearly flawless. The Centaur main engine cutoff occurred within 2.1 seconds of predicted, and Centaur second main engine cutoff occurred exactly as predicted. This allowed the Voyager 2 spacecraft and the propulsion module to be injected into an accurate trajectory toward Jupiter. The propulsion module ignition and burnout were also within two seconds of that predicted. Critical launch mark events are provided in Table 3-1.

The Voyager project could not immediately enjoy the launch success, however, because of a series of abnormal spacecraft indications which were not well understood at the time. One of the spacecraft stabilizing gyroscopes appeared to be operating abnormally in initial data but began working normally as time progressed.

Another problem was with one of the attitude and articulation control subsystem (AACS) computers. The spacecraft switched to the backup computer, and problems with the AACS continued for a couple of days after launch.

Within an hour after launch, the Voyager 2 science scan platform boom was to have been fully extended and latched. The deployed maneuver sequence was executed and the boom moved outward; however, there was no signal to indicate that the boom was actually in place. After several days of analysis of the problem, it was determined that the boom was nearly fully deployed, within a half of a degree. It was ultimately decided that the sensor which provided the local signal was at fault and that the boom was fully extended.

C. VOYAGER 1 (MISSION B) LAUNCH

The Voyager 1 spacecraft was scheduled for launch on September 1, 11 days after the successful launch of Voyager 2. Because of the several postlaunch problems on Voyager 2, the launch of Voyager 1 was delayed to September 5. This allowed the Voyager 1 science boom to be inspected and allowed engineers to determine if there was a problem with the inherent science boom design. Sixteen days after Voyager 2 was launched, Voyager 1 was launched on September 5, 1977, at 8:56 a.m. eastern daylight time.

This launch was accomplished by the sweat, blood, and tears of many scientists, technicians, and managers working long hours during this time period. It was probably fitting that this last launch on a Titan Centaur vehicle, which required such intense preparation, was launched on Labor Day.

Table 3-1. Launch Mark Events for Voyager 2
Launch Day - August 20, 1977 at 14:29:44 GMT

Flight events	Nominal time from launch, min:s	Nominal time, GMT, h:min:s	Actual time, GMT, h:min:s	
SRM ignition	0:00	14:29:44	14:29:44.256	(E)
Forward bearing release	1:40.0	14:31:24	14:31:24.3	(E)
Stage I ignition	1:50.7	14:31:34	14:31:35.0	(E)
Solid rocket motor (SRM) jettison	2:02.0	14:31:46	14.31:46.2	(E)
Stage I cutoff	4:14.6	14:33:58	14:33:59.1	(E)
Stage I jettison	4:15.5	14:33:59	14:33:59.4	(E)
Stage II ignition	4:15.4	14:33:59	14:33:59.6	(E)
Centaur shroud jettison	4:26.0	14:34:10	14:34:11.3	(E)
Stage II cutoff	7:44.2	14:37:28	14:37:27.0	(E)
Stage II jettison	7:50.4	14:37:34	14:37:32.7	(E)
Centaur main engine start (MES) 1	8:00.9	14:37:44	14:37:44.3	(E)
Centaur main engine cutoff (MECO) 1	9:43	14:39:27	14:39:24.9	(E)
Centaur MES 2	52:30	15:22:15	15:22:14	(A)
Centaur MECO 2	58:08	15:27:52	15:27:52	(A)
Align to S/C separation attitude (MECO 2 + 2)	58:10	15:27:54	15:27:58.4	(K)
Arm S/C timer (MECO 2 + 101)	59:49	15:29:33	15:29:32.7	(K)
S/C separation (MECO 2 + 170)	59:58	15:30:42	15:30:42.0	(K)
S/C thrust vector control on[a]	61:00	15:30:44	15:30:53.5	(J)
Propulsion module ignition (PMI)[a]	61:13	15:30:57	15:30:58	(J)
Propulsion module burnout[a]	61:58	15:31:42	15:31:40	(J)
Start of S/C turndown[a]	62:13	15:31:57	15:31:58.7	(J)
End S/C turndown[a]	63:01	15:32:45	15:33:41.7	(J)
Propulsion module/mission Module (PM/MML) separation[a] (PMI + 772 seconds)	73:17	15:43:01	15:43:01	(J)

[a] The last six mark event times were determined by the JPL Mission Operations System.
(E) = ETR (A) = ARIA (K) = KSC (J) = JPL

Voyager 1 was on a shorter and faster trajectory than Voyager 2 and overtook this spacecraft near the asteroid belt. Voyager 1 arrived at Jupiter in March of 1979, four months ahead of Voyager 2.

This launch was an historic occasion for another reason. This was the last launch of a Titan Centaur vehicle, and all the previous Titan Centaurs had performed nearly flawlessly, providing good accuracy to the planetary spacecraft which they carried. The five other planetary spacecraft launched by Titan Centaur were Helios 1 and 2, Viking 1 and 2, and Voyager 2. The Titan Centaur combination on this last launch again provided a final injection which was very accurate but not without some nervous moments.

The Titan performance was lower than expected, and the Centaur burned 16 seconds longer than planned during its first burn to make up for the Titan underperformance. The Centaur second burn was within one second of the planned time, and spacecraft separation also occurred within a second of the planned time. The propulsion module burn, which was planned to be 45 seconds, burned almost exactly as planned but occurred approximately 3 seconds later than planned. In all, the Titan Centaur propulsion module combination provided a very accurate trajectory to Jupiter. Critical launch mark events are provided as Table 3-2.

Table 3-2. Launch Mark Events for Voyager 1
Launch Day - September 5, 1977 at 12:56 GMT

Flight events	Nominal time from launch min:s	Nominal time, GMT, h:min:s	Actual time, GMT, h:min:s
SRM ignition	0:00	12:56:00	12:56:00.958 (E)
Forward bearing release	1:40.0	12:57:40	12:57:41.0 (E)
Stage I ignition	1:50.7	12:57:50.7	12:57:53.3 (E)
Solid rocket motor (SRM) jettison	2:02.0	12.58:02	12.58:04.3 (E)
Stage I cutoff	4:19.7	13:00:19.7	13:00:22.43 (E)
Stage I jettison	4:20.5	13:00:20.5	13:00:23.15 (E)
Stage II ignition	4:20.5	13:00:20.5	13:00:23.10 (E)
Centaur shroud jettison	4:31.0	13:00:31	13:00:35.02 (E)
Stage II cutoff	7:50.1	13:03:50:1	13:03:51.45 (E)
Stage II jettison	7:56.2	13:03:56.2	13:03:55.24 (E)
Centaur main engine start (MES) 1	8:06.7	13:04:06.7	13:04:05.68 (E)
Centaur main engine cutoff (MECO) 1	9:38.5	13:05:38.5	13:05:54.98 (E)
Centaur MES 2	53:01	13:49:01	13:49:22.5 (K)
Centaur MECO 2	58:54.3	13:54:54.3	13:54:56 (A)
Align to S/C separation attitude (MECO 2 + 2)	58:56.5	13:54:56.5	Not Available
Arm S/C timer (MECO 2 + 101)	60:35.5	13:56:35.5	13:56:37.6 (V)
S/C separation (MECO 2 + 170)	61:44.5	13:57:44.5	13:57:49 (A)
S/C thrust vector control on[a]	61:46.5	13:57:46.5	13:58:03 (J)
Propulsion module ignition (PMI)[a]	61:59.5	13:57:59.5	13:58:03.18 (J)
Propulsion module burnout[a]	62:44.5	13:58:44.5	13:58:48.22 (J)
Start of S/C turndown[a]	62:59.5	13:58:59.5	13:59:09 (J)
End S/C turndown[a]	63:47.5	13:59:47.5	14:00:57 (J)
Propulsion module/mission Module (PM/MM) separation[a] (PMI + 722 seconds)	74:01.5	14:10:01.5	14:10:05.946 (J)

[a] The last six mark event times were determined by the JPL Mission Operations System.
(E) = ETR (K) = KSC (A) = ARIA (V) = Vanguard (J) = JPL

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SECTION IV

NEAR-EARTH PHASE NETWORK SUPPORT

A. INTRODUCTION

The Near-Earth Tracking and Data System was the integration of several support agencies to accomplish the task of providing ground data system support from the prelaunch period through the Deep Space Network two-way acquisition. The Near-Earth Phase Network was responsible for the acquisition, distribution, and processing of spacecraft and launch vehicle telemetry and metric data. For the Voyager mission, JPL headed the Near-Earth Tracking and Data System team and was directly responsible to the Tracking and Data System Manager. The agencies providing computer support, communications, and station support were Kennedy Space Center, Goddard Space Flight Center, and the Department of Defense. The Goddard support included National Aeronautics and Space Administration (NASA) Communications, tracking support from Spacecraft Tracking and Data Network (STDN), and Goddard computer support. The Department of Defense resources included support from the Eastern Test Range (ETR), the 4950th Test Wing at Wright Patterson Air Force Base for Advanced Range Instrumentation Aircraft (ARIA), and the U. S. Army Kwajalein Missile Range for support by Kwajalein sites. The Eastern Test Range provided radio metric and telemetry support from stations at Cape Canaveral, Merritt Island, Bahama Island, Grand Turk Island, Antigua, and Ascension Island. The ETR provided navigation and predicts support for the near-earth phase from the Real-Time Computer System at the Cape Canaveral Air Force Station.

The Kennedy Space Center provided launch vehicle telemetry integration and data processing and display information.

The Goddard Space Flight Center (GSFC) Spaceflight Tracking and Data Network provided support with stations located at Merritt Island, Bermuda, Ascension, Guam, Hawaii, and Vandenberg. The Wright Patterson Air Force Base support was provided by four ARIA. These aircraft provided both launch vehicle and spacecraft telemetry coverage.

The JPL team at the Cape provided the overall planning and coordination of the activities required to provide near-earth tracking and data support for the project.

B. VOYAGER 2 LAUNCH SUPPORT

1. General Summary

The Near-Earth Tracking and Data System provided ground data system support for four telemetry links, radio metric data, and real-time data and communications support to the entire network. It also provided navigation data, real-time acquisition data, and predicts.

The coordination for the comprehensive and intensive support effort which occurred during the near-earth launch interval was coordinated through a complex voice network, which is depicted in Figure 4-1. The Voyager 2 ground track and summary station support intervals are provided in Figure 4-2. The key near-earth launch mark events are summarized in Table 3-1.

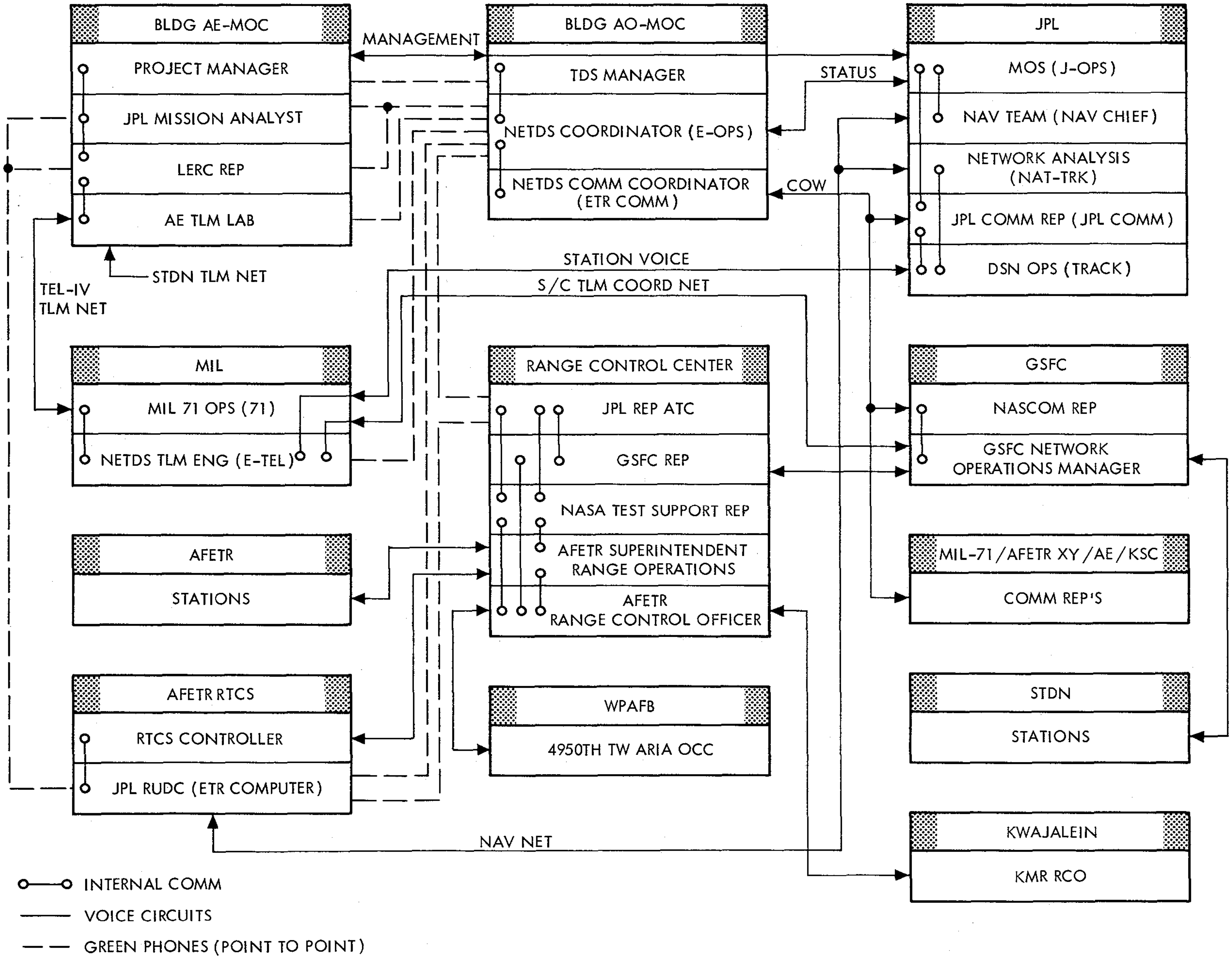
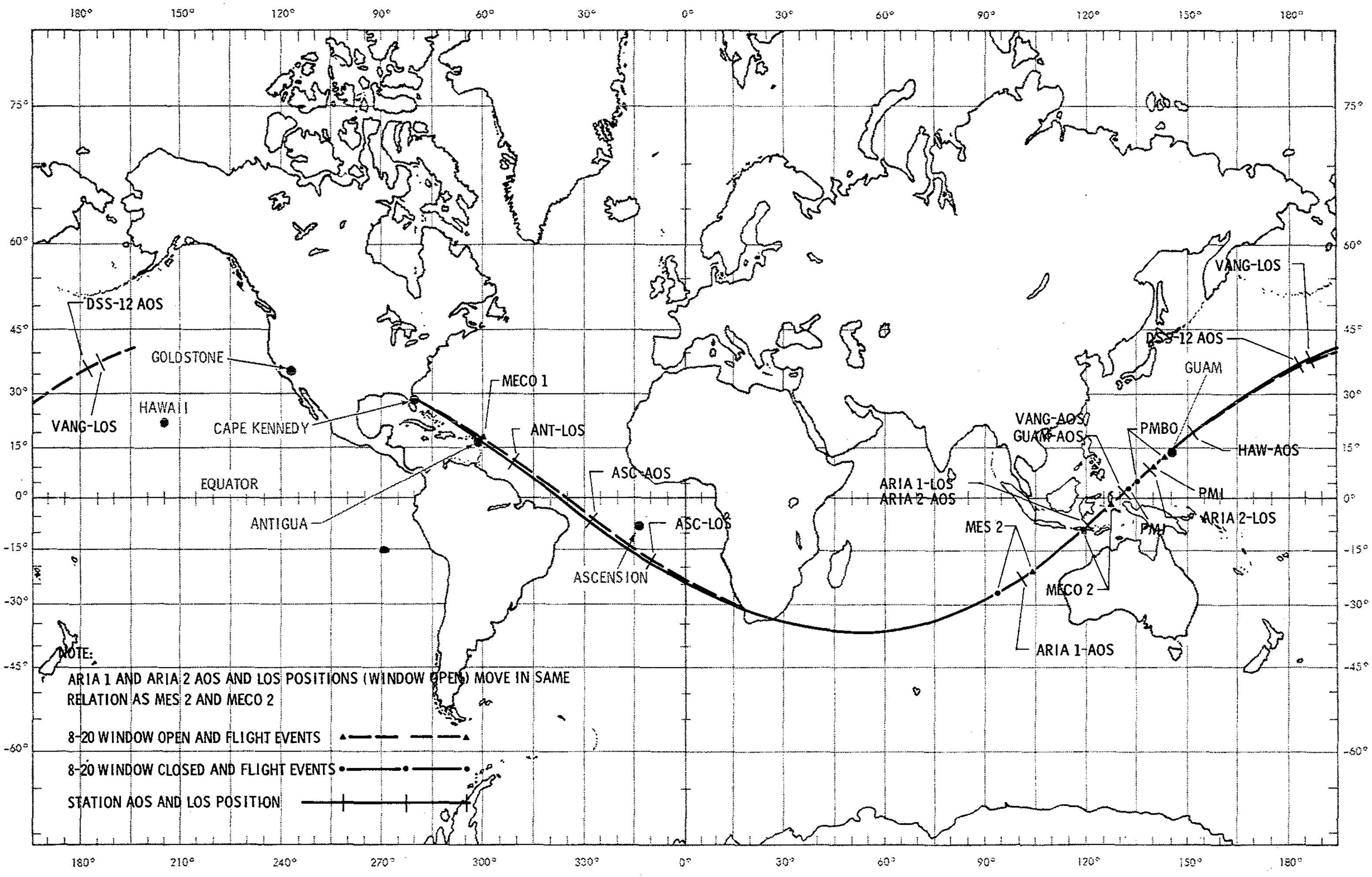


Figure 4-1. Near-Earth Tracking and Data System Operational Control Communications Interfaces



NOTE:
ARIA 1 AND ARIA 2 AOS AND LOS POSITIONS (WINDOW OPEN) MOVE IN SAME RELATION AS MES 2 AND MECO 2

Figure 4-2. Earth Track for Voyager 2 Launch of 20 August 1977

2. Launch Vehicle Telemetry Support

During the launch on August 20, 1977, launch vehicle telemetry support was provided on two different radio links. The first was a Titan link at 2287.5 MHz, and support was provided from ETR telemetry stations only. A Centaur telemetry data stream at 2202.5 MHz was also required by the launch vehicle system. Tracking support of this link was provided by the Eastern Test Range, Spaceflight Tracking and Data Network, and ARIA. The expected versus actual coverage for all stations supporting the Titan and Centaur launch vehicle telemetry is provided in Tables 4-1, 4-2, and 4-3.

3. Spacecraft Telemetry Support

The spacecraft telemetry support was also provided on two separate radio links. The spacecraft link was extracted from the Centaur 2202.5 MHz link from launch into spacecraft separation from Centaur. The spacecraft telemetry data extracted were at 40 bits per second. These data were transmitted from the stations, in real-time, to Merritt Island, where they were reformatted and transmitted to the JPL Mission Control and Computing Center. The spacecraft link at 2295.0 MHz was also provided from launch to initial DSN two-way acquisition. This link was initially at 40 b/s but switched to 1200 b/s before the propulsion module burn to allow high-rate telemetry data during this period of time. The stations supporting the 1200 b/s data via the spacecraft link were Vanguard and Hawaii. The overall spacecraft telemetry planned versus actual coverage is provided in Table 4-4.

4. Radio Metric Data Support

Both Eastern Test Range and Spacecraft Tracking Data Network stations were used to provide radio metric data on the launch vehicle. The Centaur carried a C-band beacon at a frequency of 5765 MHz.

Table 4-1. ETR Launch Vehicle, Spacecraft and Metric Data Coverage for Voyager

Station (type)	Link	Expected coverage estimates, Time from launch, min:S	Actual coverage provided, Time from launch, min:s	Comments
TEL - IV (telemetry)	2202.5	0:00 - 7:30	0:00 - 8:22	
(Cape Canaveral telemetry)	2287.5	0:00 - 7:30	0:00 - 8:22	
	2295.0	0:00 - 3:20[a]	0:00 - 7:00	See Note 1
Cape (radar)	5765.0	0:12 - 6:01	0:00 - 6:12	
Merritt Island (radar)	5765.0	0:14 - 7:20	0:12 - 8:10	
Patrick (radar)	5765.0	0:21 - 7:26	0:18 - 8:28	
Grand Bahama (telemetry)	2202.5	1:10 - 8:20	0:41 - 8:20	
	2287.5	1:10 - 8:20	0:41 - 8:20	See Note 2
	2295.0	1:10 - 4:20[a]	0:41 - 8:20	
Grand Bahama (radar)	5765.0	1:24 - 7:48	1:05 - 8:28	
Grand Turk (telemetry)	2202.5	4:30 - 10:20	3:08 - 11:04	
	2287.5	4:30 - 8:20	2:55 - 10:02	See Note 2
	2295.0	4:30 - 7:30[a]	3:44 - 9:57	
Grand Turk (radar)	5765.0	4:13 - 10:18	3:31 - 11:05	
Antigua (telemetry)	2202.5	6:49 - 12:50	6:10 - 13:22	
	2287.5	6:49 - 8:20	6:10 - 10:00	See Note 2
	2295.0	6:49 - 9:50[a]	6:10 - 13:20	
Antigua (radar)	5765.0	7:09 - 12:52	6:34 - 13:32	
Ascension (telemetry)	2202.5	21:10 - 25:55	20:30 - 26:35	
	2295.0	21:10 - 23:40[a]	20:30 - 26:35	
Ascension (12.16)	5765.0	21:24 - 25:40	20:17 - 26:20	
Ascension (12.15)	5765.0	21:24 - 25:40	20:40 - 25:40	

[a] S/C link expected to be lost at this time due to signal being obscured by high-gain antenna.

Note 1: 30-second loss of data starting at 3:50, for actual coverage

Note 2: Titan link 2287.5 committed to Titan Centaur separation plus 20 seconds.

Table 4-2. STDN Launch Vehicle, Spacecraft and Metric Data Coverage for Voyager

Station (type)	Link	Expected coverage estimates, Time from launch, min:S	Actual coverage provided, Time from launch, min:s	Comments
Merritt Island (telemetry)	2202.5	0:00 - 7:30	0:00 - 8:25	
	2287.5	0:00 - 7:30	0:00 - 8:26	
	2295.0	0:00 - 3:20	0:00 - 8:11	Note 1
Bermuda (telemetry)	2202.5	5:20 - 9:30	6:12 - 9:47	Note 2
	2287.5	5:20 - 8:20	5:00 - 10:01	
	2295.0	5:20 - 7:25	4:50 - 10:03	Note 1
Bermuda (radar)	5765.0	5:38 - 9:12	4:24 - 10:16	
Ascension (telemetry)	2202.5	22:40 - 26:05	21:31 - 26:33	See Note 3
	2295.0	22:40 - 24:20	21:15 - 26:33	See Notes 1 & 3
Vanguard (telemetry)	2202.5	59:39 - 61:15	59:25 - 61:49	See Note 4
	2295.0	59:39 - 83:00	59:43 - 83:11	See Note 5
Vanguard (radar)	5765.0	59:39 - 69:44	58:52 - 96:52	
Guam (telemetry)	2202.5	59:43 - 61:15	No valid data	See Note 6
	2295.0	59:43 - 83:00	No valid data	See Note 6
Hawaii (telemetry)	2202.5	None	None	
	2295.0	65:41 - 83:00	65:46 - 83:12	See Note 5
Hawaii (radar)	5765.0	Not committed	65:26 - 123:21	

Note 1: S/C link expected to be lost at this time due to signal being obscured by high-gain antenna.

Note 2: Bermuda had low elevation pass on this trajectory.

Note 3: Entered keyhole at 14:54:07 for 41 seconds.

Note 4: Centaur link committed until propulsion module ignition.

Note 5: Valid data until spacecraft switch to 7.2 kb/s downlink.

Note 6: Unable to obtain solid receiver lock due to side lobe tracking. Problem was caused by invalid acquisition data.

Table 4-3. ARIA Launch Vehicle and Spacecraft Telemetry Coverage for Voyager

Station (type)	Link	Expected coverage estimates, Time from launch, min:S	Actual coverage provided, Time from launch, min:s	Comments
ARIA 4 (telemetry)	2202.5	42:14 - 47:22	44:00 - 47:35	Decom lock/unlock (Note 1)
	2295.0	41:02 - 44:17	40:58 - 44:30	See Note 2
ARIA 1 (telemetry)	2202.5	50:56 - 55:54	50:35 - 56:18	Decom lock/unlock (Note 1)
	2295.0	49:44 - 53:26	48:17 - 53:40	See Note 2
ARIA 3 (telemetry)	2202.5	50:56 - 55:54	50:40 - 56:20	Decom lock/unlock (Note 1)
	2295.0	49:44 - 53:26	47:45 - 53:45	See Note 2
ARIA 2 (telemetry)	2202.5	55:42 - 60:37	55:40 - 63:10	Decom lock/unlock (Notes 1 & 3)
	2295.0	54:46 - 57:42	53:00 - 57:39	See Note 2
			62:48 - 65:05	See Note 3

Note 1: Launch vehicle telemetry data decommutator lock/unlock times. This data valid for S/C telemetry data to be stripped out and sent to MIL 71 in real-time.

Note 2: S/C link expected to be lost at this time due to signal being obscured by high-gain antenna.

Note 3: S/C signal reacquired after spacecraft turndown, which points antenna toward earth.

Other comments: ARIA 1 could not phase right-hand circular polarization but tracked using left-hand circular polarization. ARIA 3 data was transmitted in real-time because ARIA 1 could not track in the standard configuration.

Table 4-4. Summary of Spacecraft Telemetry Data Available at MIL 71 for Transmission to JPL

Station	Data (b/s)	Percentage of solid lock data planned versus actual	Number of data dropouts	Seconds of data loss during dropout
Merritt Island	40	100	0	0
Antigua	40	110.4	0	0
Ascension	40	96.8	2	25
ARIA #3	40	116.1	1	10
ARIA #2	40	100	0	0
Vanguard	1200	100	0	0
Hawaii	40	100	0	0

Note: Overall real-time data flow of spacecraft data to MIL 71 from the Near-Earth Phase Network (NEPN) stations was excellent.

Eleven radars supported the Voyager 2 launch. These stations consisted of Merritt Island, Patrick Air Force Base, Cape Radar, Grand Bahama Island, Bermuda, Grand Turk Island, Antigua, Ascension (two radars), Vanguard, and Hawaii. All radio metric data were transmitted to the Eastern Test Range real-time computer system (RTCS) where the data were processed and used to compute acquisition data, early definition of the Centaur parking orbit, and the Centaur transfer orbit. In addition a one-hour span of Goldstone (DSS 12) high-speed metric data was sent to the real-time computer facility for use in obtaining an estimate of the spacecraft orbit. The radio metric system configuration and data flow is provided in Figure 4-3. This configuration includes the real-time and near-real-time data acquisition flow between the Eastern Test Range, its supporting stations, and the Goddard Network. The real-time computer system using the metric data from the Centaur beacon and spacecraft transponder computed:

(1) Spacecraft acquisition data for use by the DSN

(2) Orbital elements

(3) Jupiter B plane maps.

These computations are summarized in Table 4-5.

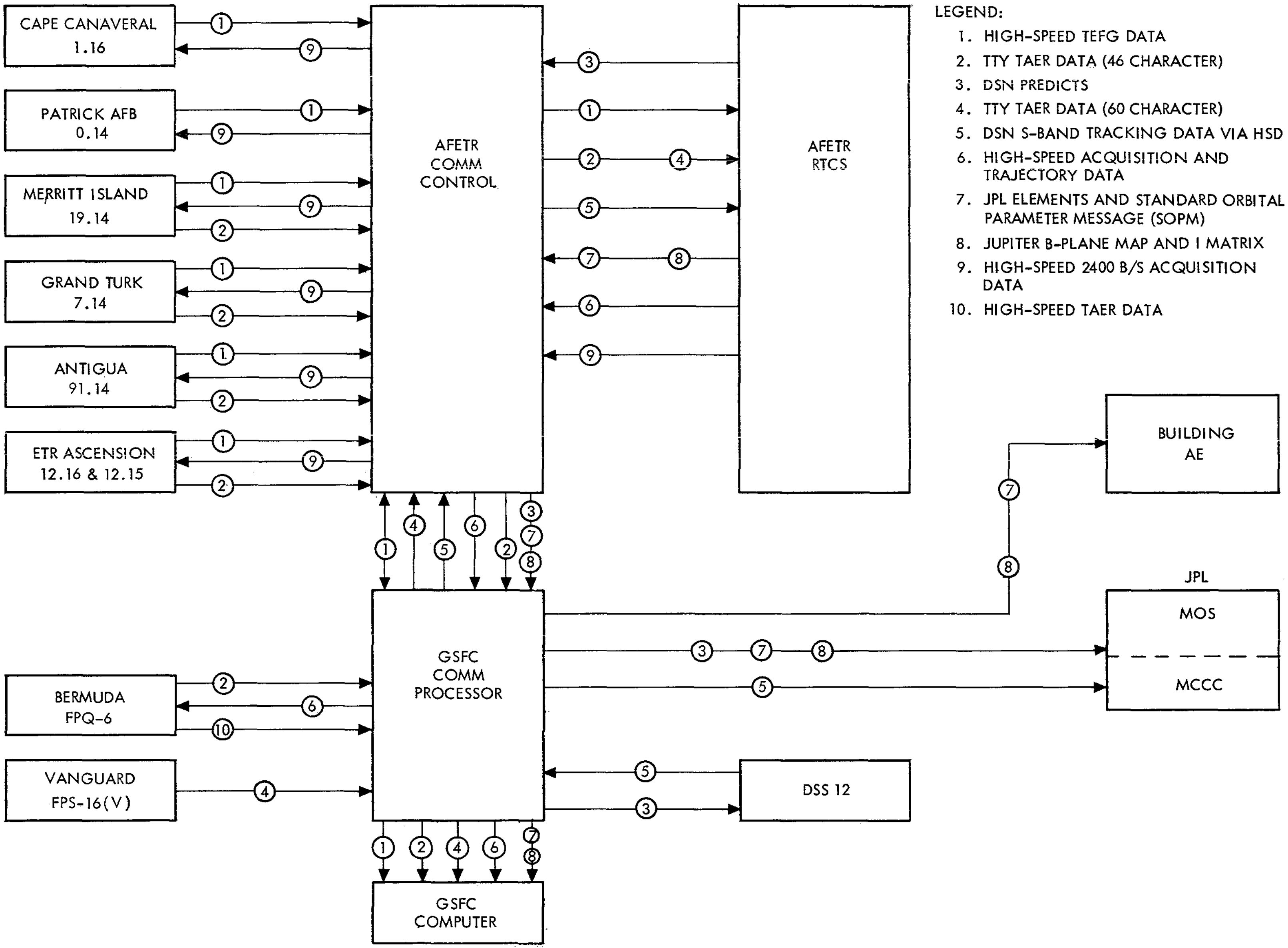


Figure 4-3. Near-Earth Radio Metric System Configuration

Table 4-5. Summary of RTCS Computations for JPL

Time from launch, min	Data source	Data generated at RTCS
-45	Nominal orbital elements from polynomials	Predicts for DSN stations: Goldstone (DSS 12 and DSS 11) and Honeysuckle (DSS 44) (Set 01N)
+4	Liftoff and azimuth as specified	Liftoff time message
+9.8	MECO 1	
+20	Antigua data	Orbital elements on Centaur parking orbit (JPL and standard orbital parameter message, SOPM)
+58.6	MECO 2	
+75	Vanguard data plus nominal PM burn	Orbital elements on Centaur second burn plus nominal PM burn (JPL and SOPM)
+80	Vanguard data plus nominal PM burn	Predicts for DSN stations: DSS 12, 11, 44 (Set 01A)
+90	Vanguard data plus nominal PM burn	Jupiter B-plane mapping
+100	Vanguard data	Orbital elements on Centaur tranfer orbit (JPL and SOPM)
+110	Vanguard data	I-matrix on Centaur transfer orbit
+155	DSS 12 data	Orbital elements on spacecraft orbit (JPL and SOPM)
+165	DSS 12 data	Jupiter B-plane mapping
+180	DSS 12 data	Predicts for DSN stations: DSS 12, 11, 44 (Set 02A)
+195	DSS 12 data	I-Matrix on spacecraft orbit

5. Communications Support

The Voyager project communications requirements during the near-earth phase were for voice, teletype, high-speed data, and wideband data circuits between the supporting stations and mission operations control centers.

The primary communications resources were the Air Force Eastern Test Range, the Kennedy Space Center, and the NASA Communications Network. These resources were used to provide high-quality voice circuits for the Voyager near-earth support period and exceptional real-time launch vehicle telemetry, spacecraft telemetry, and radiometric data support during the near-earth period. The ARIA and Centaur communications were comprised of communications which required circuits half way around the world.

The high-speed and wideband circuit configurations between JPL, Cape Canaveral, and Cape Kennedy are provided in Figure 4-4. The Cape-to-JPL voice circuits for prelaunch and launch are given in Figure 4-5.

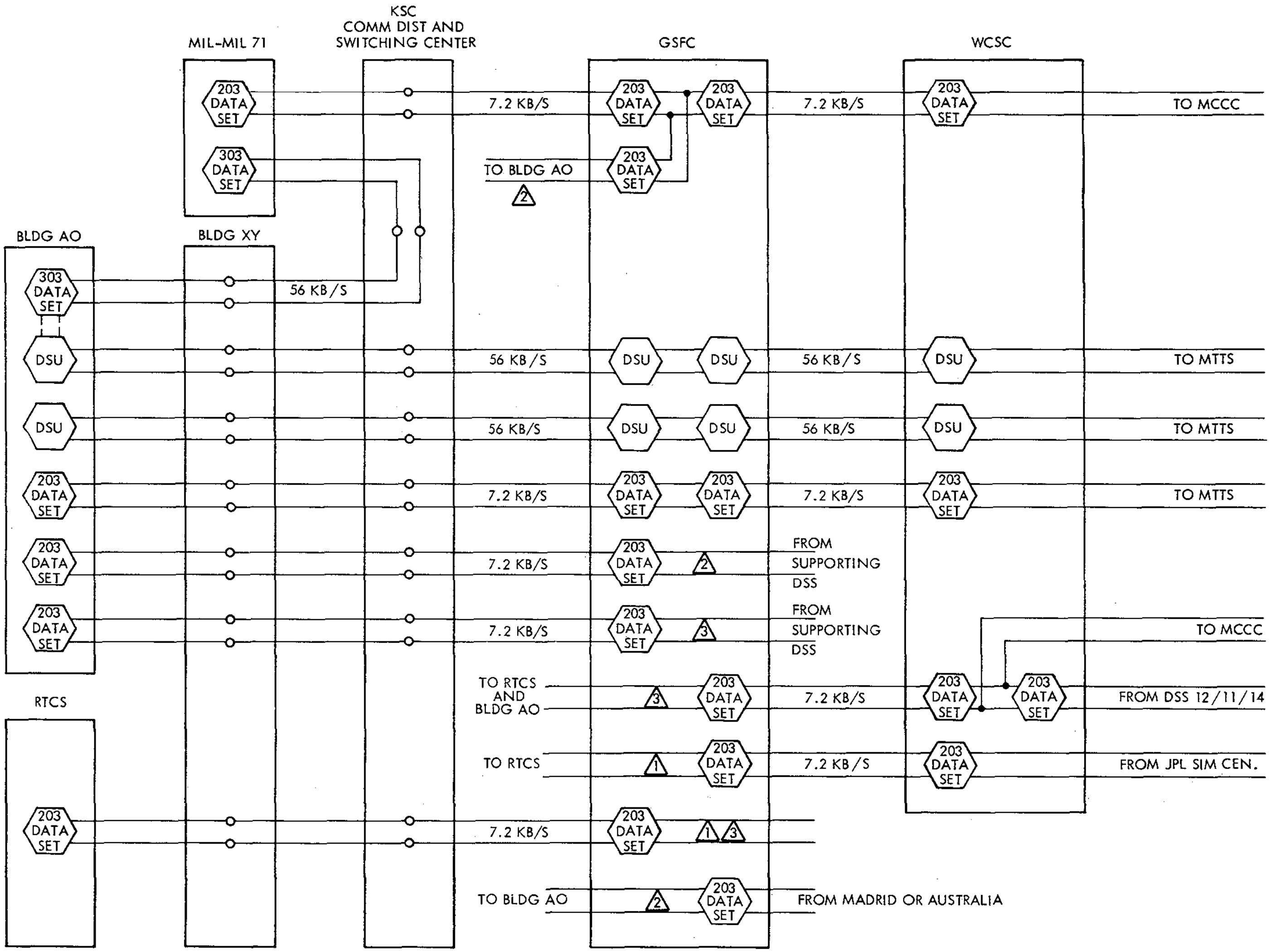
A few months preceding launch it became a Voyager requirement to have Voyager spacecraft data remoted from JPL back to the Cape for a period of time after launch. This system required a voice circuit, a high-speed data communications line, and dual 56 kb/s data circuits.

6. Problems and Corrective Action

All ETR stations and the ARIA exceeded their planned coverage, and no significant problems were encountered with any of the Department of Defense (DOD) resources.

The few problems that were encountered were with the Goddard STDN stations. The most significant of these problems was the failure of Guam to acquire the spacecraft launch vehicle and telemetry link. Guam provided no useable data whatsoever during their pass. Post-test analysis indicates that the acquisition data provided by the Goddard Space Flight Center was invalid and this caused the station to lock on a telemetry side lobe.

Another problem of much less significance was the Bermuda station acquiring good data later than anticipated on the Centaur link. This late acquisition was traced directly to their low elevation pass and corresponding weak signal.

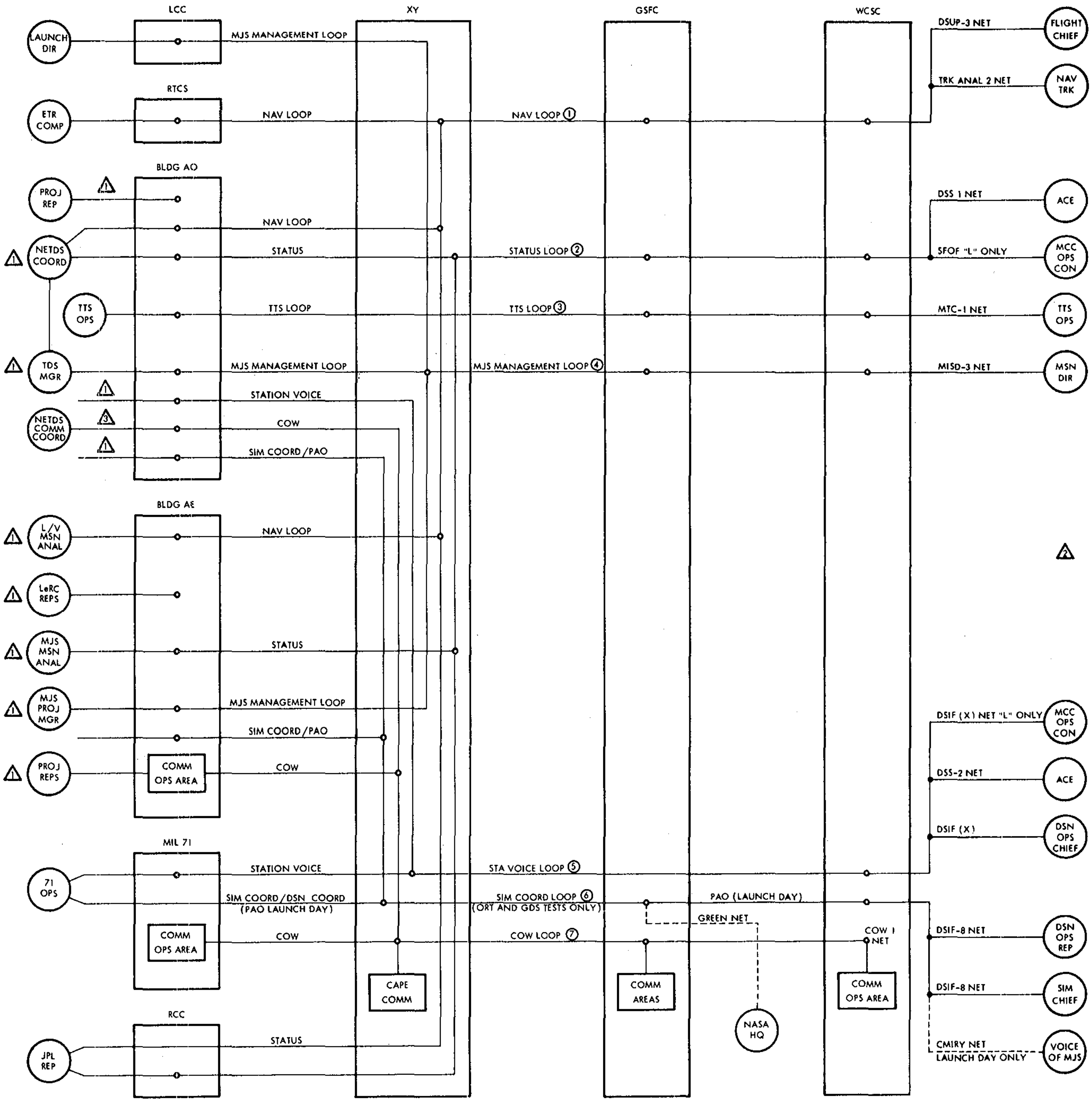


1 DSS-12 7.2 KB/S DATA OR JPL SIM CEN DATA CONNECTED TO RTCS 7.2 KB/S CIRCUIT AS REQUESTED BY NETDS COMM COORD

2 MIL-71 7.2 KB/S DATA BACKFEED FROM MADRID OR AUSTRALIA CONNECTED TO BLDG AO TTS AS REQUESTED BY NETDS COMM

3 JPL BACKFEED OF DSS-12 DATA WILL INCLUDE BOTH TELEMETRY AND METRIC DATA AND IS TO BE CONNECTED TO BLDG AO TTS WHEN REQUESTED BY NETDS COMM COORD

Figure 4-4. JPL-Cape-MIL High-Speed Data Flow Configuration



△1 INTERNAL DISTRIBUTION OF VOICE CIRCUITS WITHIN BLDG AO AND AE WILL BE SHOWN IN GREATER DETAIL IN COMM SECTION OF THE MOP/LOP

△2 FOR INTERNAL JPL INTERCONNECTS, REFER TO DSN OPERATIONS PLAN, 618-700

△3 RECEIVES ALL VOICE LONG LINES

Figure 4-5. Cape-to-JPL Voice Circuits for Prelaunch and Launch

C. VOYAGER 1 LAUNCH SUPPORT

1. General Summary

The near-earth tracking data system configuration for the Voyager 1 launch was very similar to the Voyager 2 configuration. The major differences were in the specific stations supporting. During the first launch, Ascension Island Stations supported the launch vehicle and telemetry links. These stations were not used for the second launch but were replaced by Kwajalein. Also during the first launch, four ARIA were used, and during the second launch, only three ARIA were used. The ARIA supported from somewhat different locations also, although the primary staging bases were in Australia for both launches. The Vanguard was also moved to a new location for the second Voyager launch on September 5, 1977.

The overall state of readiness and complexity of support were very similar in almost all respects. The coordination effort which tied together this multi-agency integrated support was again very similar to that effort on the Voyager 2 launch. The complex voice network configuration for accomplishing this task is described in Figure 4-1.

The Voyager 1 representative ground track and summary station support intervals are provided in Figure 4-6.

The key near-earth mark events during the Voyager 1 launch period are summarized in Table 3-2. One mark event was considerably different from the planned nominal time. This was Centaur main engine cutoff number one. This mark event was 16 seconds later than planned and was caused by the Centaur burning longer to make up for a negative Titan vehicle performance.

2. Launch Vehicle Telemetry Support

The launch vehicle telemetry support for the Voyager 1 launch on September 5, 1977, was very similar to the first launch. The same two telemetry radio frequencies were used, 2287.5 MHz for the Titan link and 2202.5 MHz for the Centaur telemetry link. The expected versus actual coverage for all stations supporting the Titan and Centaur launch vehicle telemetry is provided in Tables 4-6, 4-7, and 4-8.

3. Spacecraft Telemetry Support

The project required spacecraft telemetry data support from liftoff through all station view periods until initial DSN acquisition. The primary spacecraft data configuration during the early portion of the mission until spacecraft-Centaur separation was spacecraft 40 b/s data combined with the Centaur telemetry stream. Spacecraft data were extracted from the Centaur 2202.5 MHz link at the station and transmitted to the JPL MIL 71 facility where they were reformatted and transmitted to the JPL Mission Control and Computing Center. The spacecraft link at 2296.74 MHz was also provided from launch to initial DSN two-way acquisition. This link was at 40 b/s through the initial Titan and Centaur phases but switched to 1200 b/s before the propulsion module burn. Spacecraft data via the spacecraft link was the prime link after Centaur spacecraft separation. The high-rate 1200 b/s spacecraft

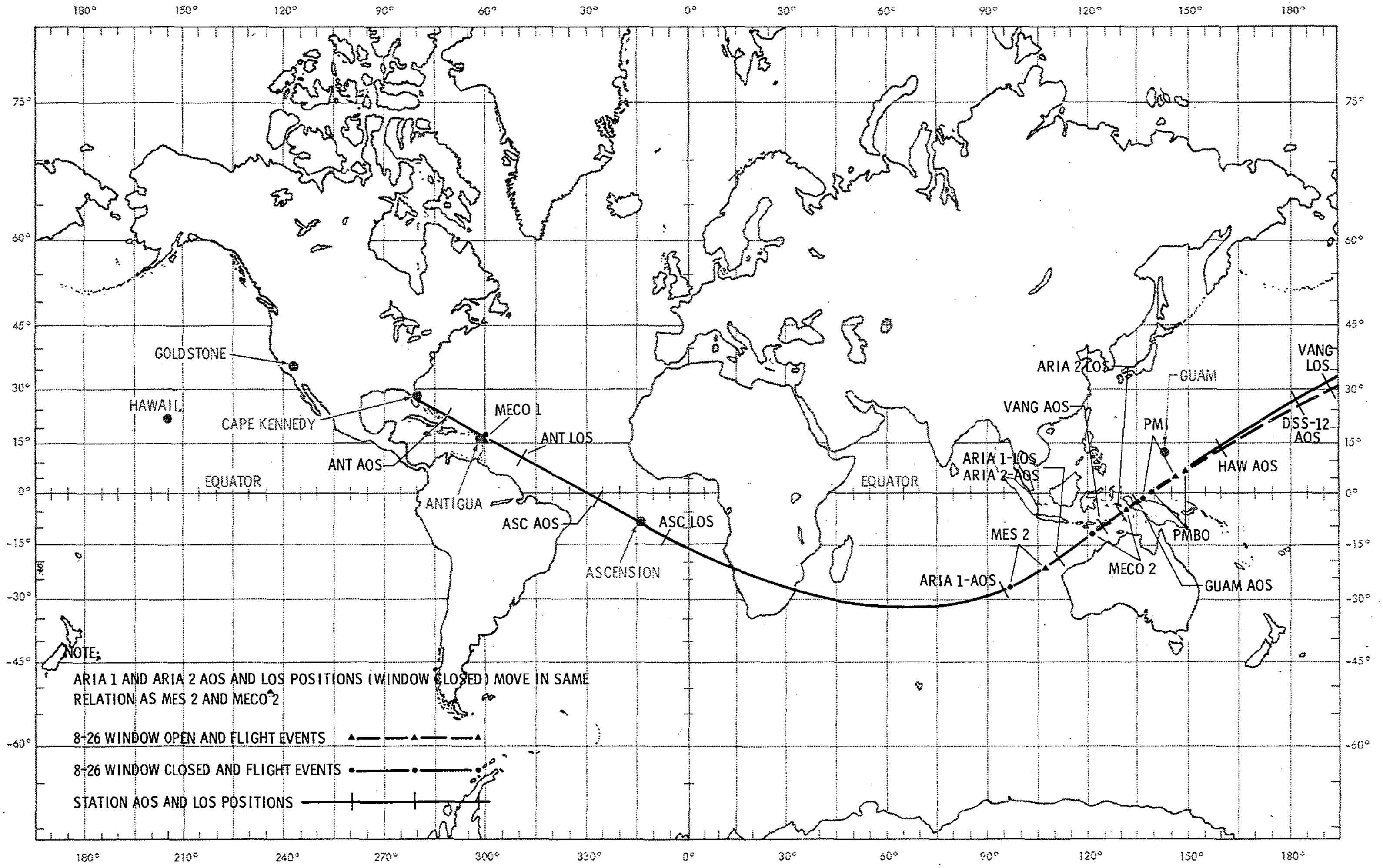


Figure 4-6. Earth Track for Voyager 1 Launch

Table 4-6. ETR and Kwajalein Launch Vehicle, Spacecraft and Metric Data Coverage for Voyager

Station (type)	Link	Expected coverage estimates, Time from launch, min:S	Actual coverage provided, Time from launch, min:s	Comments
TEL - IV (telemetry)	2202.5	0:00 - 7:30	0:00 - 8:20	
	2287.5	0:00 - 7:30	0:00 - 8:20	
	2296.4	0:00 - 3:20*	0:00 - 7:40	
Cape (radar)	5756.0	0:16 - 6:01	0:00 - 6:16	
Merritt Island (radar)	5765.0	0:14 - 7:23	0:12 - 8:17	Note 1
Patrick (radar)	5765.0	0:21 - 7:25	0:16 - 8:22	
Grand Bahama (telemetry)	2202.5	1:10 - 8:00	0:57 - 8:55	
	2287.5	1:10 - 8:00	0:57 - 8:55	
	2296.4	1:10 - 4:20[a]	0:57 - 8:20	
Grand Bahama (radar)	5765.0	1:24 - 7:56	1:07 - 8:45	
Grand Turk (telemetry)	2202.5	4:06 - 9:29	3:26 - 10:25	
	2287.5	4:06 - 8:16[b]	3:26 - 10:25	
	2296.4	4:06 - 6:40[a]	3:26 - 10:25	
Grand Turk (radar)	5765.0	4:23 - 9:31	3:57 - 10:27	
Antigua (telemetry)	2202.5	7:28 - 11:20	6:40 - 12:30	
	2287.5	7:28 - 8:16[b]	6:40 - 12:30	
	2296.4	7:28 - 9:40[a]	6:40 - 12:30	
Antigua (radar)	5765.0	7:46 - 11:23	7:15 - 12:43	
Kwajalein	2202.5	61:05 - 61:53[c]	61:58 - 64:18	Note 2
	2296.4	61:05 - 83:00	61:58 - 83:58	Note 2

[a] S/C link expected to be lost at this time due to signal being obscured by high-gain antenna.

[b] Titan link 2287.5 committed to Titan Centaur separation plus 20 seconds.

[c] Centaur link committed until PMI.

Note 1: Merritt Island radar lost data for 21 seconds starting at 221 seconds, because the computer program was lost and had to be reloaded.

Note 2: Kwajalein acquired both links 53 seconds late. Spacecraft solid-lock data indication was not reported until 66 minutes 43 seconds after launch. This was later reported as an equipment problem, and the data were good on the magnetic tape.

Table 4-7. STDN Launch Vehicle, Spacecraft and Metric Data Coverage for Voyager

Station (type)	Link	Expected coverage estimates Time from launch, min:s	Actual coverage provided Time from launch, min:s	Comments
Merritt Island (telemetry)	2202.5	0:00 - 7:30	0:00 - 8:25	
	2287.5	0:00 - 7:30	0:00 - 8:26	
	2296.4	0:00 - 3:20	0:00 - 8:11	
Bermuda (telemetry)	2202.5	5:10 - 10:50	4:54 - 11:26	
	2287.5	5:10 - 8:16[b]	4:54 - 11:21	
	2296.4	5:10 - 8:10[a]	4:53 - 11:15	
Bermuda (radar)	5765.0	5:11 - 10:40	4:30 - 11:30	
Vanguard (telemetry)	2202.5	60:00 - 62:00[c]	59:55 - 62:56	
	2296.4	61:35 - 83:00[d]	61:09 - 83:57	
Vanguard (radar)	5765.0	60:00 - 70:00	61:10 - 94:00	Note 1
Guam (telemetry)	2202.5	61:20 - 62:00[c]	61:14 - 63:27	
	2296.4	61:35 - 83:00[d]	61:16 - 83:45	
Hawaii (telemetry)	2296.4	65:40 - 83:00	65:44 - 83:53	Note 2
Hawaii (radar)	5765.0	66:10 - 76:10	65:20 - 93:23	Note 3

[a] S/C link expected to be lost at this time due to signal being obscured by high-gain antenna.

[b] Titan link committed to Titan/Centaur separation plus 20 seconds.

[c] Centaur link committed until propulsion module ignition.

[d] S/C data solid lock not committed until 60 seconds after switch to 1200 b/s.

Note 1: Vanguard acquired signal 70 seconds later than predicted, tracked for approximately 2 minutes, dropped track for 6 minutes, then reacquired signal and tracked for approximately 24 minutes. Late acquisition and drop in track attributed to invalid interrange vector (IRV).

Note 2: Hawaii acquired solid data lock 4 seconds later than planned.

Note 3: Hawaii had three drops in track amounting to a total of approximately two minutes.

Table 4-8. ARIA Launch Vehicle and Spacecraft Telemetry Coverage for Voyager

Station (type)	Link	Expected coverage estimates Time from launch, min:s	Actual coverage provided Time from launch, min:s	Comments
ARIA 1 (telemetry)	2202.5	51:21 - 56:40[a]	51:46 - 57:04	Note 1
	2295.0	51:21 - 54:10[b]	49:29 - 54:20	
ARIA 3 (telemetry)	2202.5	51:21 - 56:40[a]	52:10 - 56:46	Note 1
	2295.0	51:21 - 54:10[b]	48:31 - 54:38	
ARIA 2 (telemetry)	2202.5	56:09 - 61:06[a]	58:36 - 64:02	Note 2
	2295.0	56:09 - 58:50[b]	54:14 - 57:39	Note 2
			63:58 - 66:53	Note 3

[a] Launch vehicle telemetry data decommutator lock/unlock times. These data were valid for S/C telemetry data to be stripped out and sent to MIL 71 in real-time.

[b] S/C link expected to be lost at this time due to signal being obscured by high-gain antenna.

Note 1: ARIA 1 and 3 recorded the Centaur link before the expected coverage times; however, good data lock was not obtained until 25 seconds and 49 seconds later than expected because of weak Centaur signal. They tracked the spacecraft link longer than expected.

Note 2: ARIA 2 acquired the vehicle on the spacecraft link (2296.4) and switched to the Centaur link as planned. The Centaur signal was weak and autotrack could not be maintained, causing loss of track on both links. ARIA 2 reacquired on the Centaur link about 1 minute later.

Note 3: S/C signal reacquired after spacecraft turndown, which pointed antenna toward earth.

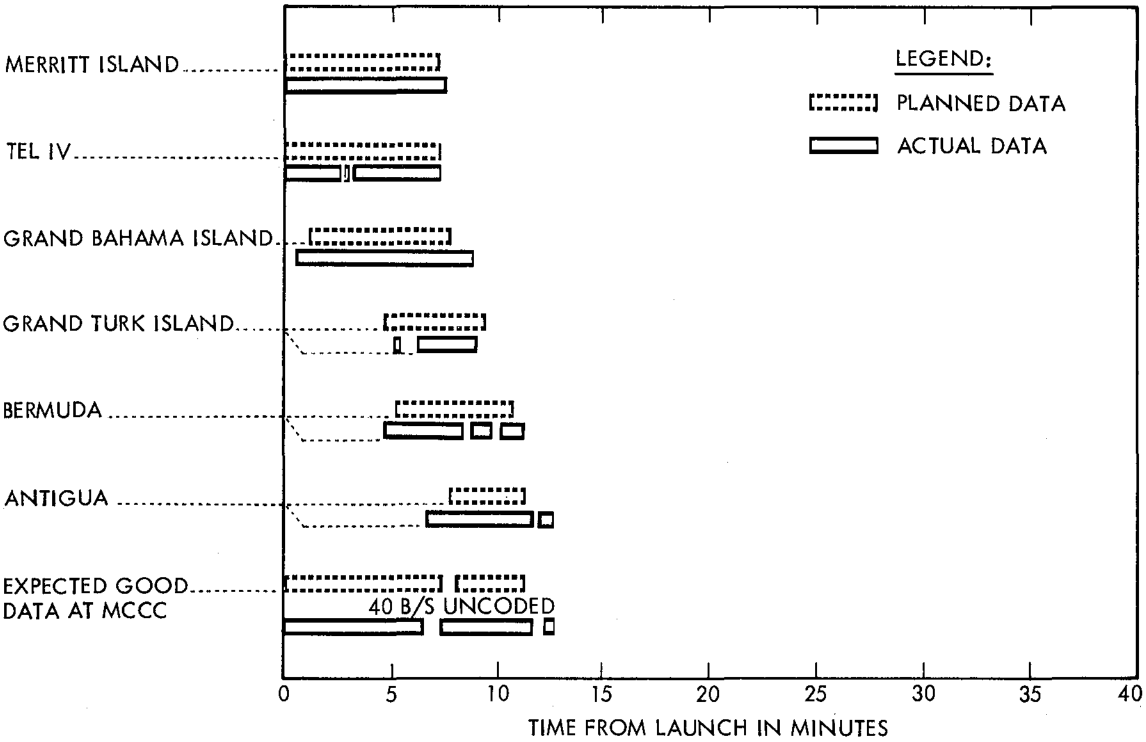
engineering data allowed detailed telemetry information on the propulsion module burn to be provided in near-real-time. The stations supporting the 1200 b/s data via the spacecraft link were Vanguard, Guam, and Hawaii. The overall spacecraft telemetry plan, actual coverage, and MIL 71 telemetry data flow to JPL are provided in Figure 4-7.

4. Radio Metric Data Support

The Eastern Test Range and the Spacecraft Tracking and Data Network were both used to provide radio metric data on the launch vehicle. A 5765 MHz C-band beacon was provided for tracking the Centaur vehicle. The DSN station at Goldstone also provided spacecraft radio metric data to the ETR real-time computer facility on the Goldstone first pass. Nine radars supported the Voyager 1 launch. These stations consisted of Merritt Island, Patrick Air Force Base, Cape Canaveral, Grand Bahama Island, Bermuda, Grand Turk Island, Antigua, Vanguard, and Hawaii. Because of the launch azimuth, the two Ascension radars didn't have view on the Voyager 1 trajectory. The radar data from all ETR and STDN stations were transmitted in real-time to the Eastern Test Range Real-Time Computer System (RTCS). These data were processed and used to provide real-time acquisition data, near-real-time acquisition data, and an early definition of the Centaur parking and transfer orbits. In addition, Goldstone (DSS 12) radio metric data were used by the real-time computer facility to calculate an initial spacecraft orbit. The radio metric system configuration and data flow is essentially the same as described for the Voyager launch in Figure 4-3. The only change is the deletion of the two Ascension radars from the Voyager 1 support. The computations provided by the real-time computer facility from the Centaur beacon and the spacecraft transponder consisted of acquisition data for use by the DSN, orbital elements on the Centaur and spacecraft, and appropriate Jupiter B-plane map computations. The real-time computer facility deliverables provided to the various elements of the project are provided in Table 4-5.

5. Communications Support

The Voyager project requirements for communications were very similar during the two Voyager launch periods. Each mission required voice, teletype, high-speed data, and wideband data circuits. The combined communications resources of the Air Force Eastern Test Range, Kennedy Space Center, NASA Communications Network (NASCOM), and DOD agencies provided the complex around-the-world communications used for the Voyager missions. The communications support in general was excellent and provided outstanding real-time launch vehicle and spacecraft telemetry data for the entire near-earth period. Real-time radio metric and acquisition data were also provided by the Eastern Test Range and NASCOM with outstanding results. The real-time data from Kwajalein used Army communications from Kwajalein to Vandenberg and DOD circuits from Vandenberg to the Cape. The Centaur and spacecraft real-time communications configurations from the ARIA aircraft in the Indian Ocean and New Guinea area basically used DOD communications links. The voice circuits and telemetry communications configuration between the Cape and JPL during the launch support are again essentially the same as used for the Voyager 2 launch and are depicted in Figure 4-5.



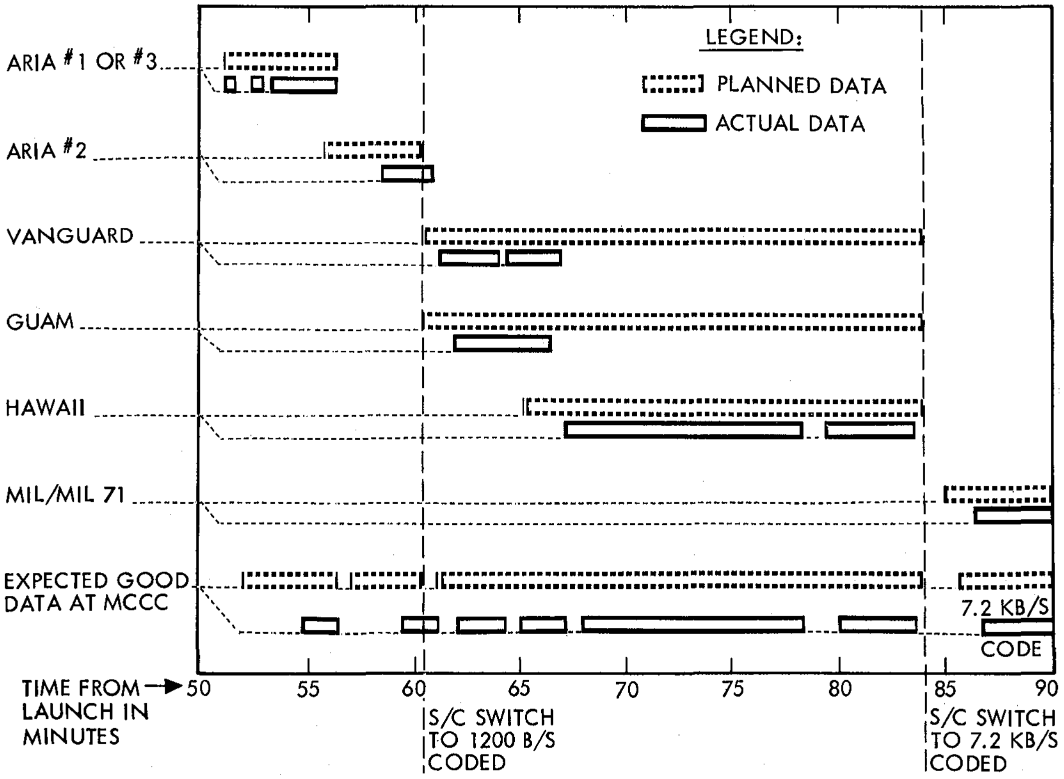


Figure 4-7. Real-Time Spacecraft Telemetry Coverage for Voyager 1 Launch

The high-speed and wideband circuit configurations between JPL, the Cape, and Merritt Island for data flow including remote high-rate telemetry data from JPL back to the Cape are found in Figure 4-4.

6. Problems and Corrective Actions

The Eastern Test Range stations, as on the Voyager 2 launch support, exceeded their planned coverage at all stations.

The Kwajalein Missile Range acquired both telemetry links 53 seconds later than expected but tracked well past the expected loss of signal time after the antennas acquired. All three ARIA tracked the spacecraft link with no problems and longer than planned. The Centaur link, however, was weak and all ARIA had trouble with decommutation lock on the Centaur link.

The Vanguard radar had a problem initially acquiring the Centaur C-band beacon. This problem was attributed to marginal acquisition data at station rise. The radar did acquire and provided 24 minutes of good tracking data, which was more than needed.

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SECTION V

INITIAL DSN ACQUISITION

A. INTRODUCTION

Initial acquisition of both Voyager spacecraft was conducted by DSS 12, with backup provided by DSS 11 and DSS 14. Both initial acquisitions went according to the plans described in Section II-E.

The geometry of the Voyager parking orbit and subsequent Jupiter transfer orbit was such that the Goldstone Deep Space Communications Complex, specifically DSS 12, became the prime initial acquisition station. This marked the first use of a Goldstone tracking station for the initial acquisition as well as the first use of a 64-meter station during an initial pass.

Minutes before the scheduled liftoff time, the Voyager 2 countdown went into a hold that was to last four minutes and 44 seconds. This delay made it imperative that tracking predictions based on the actual liftoff time be generated. These predictions were made available to the initial acquisition stations prior to spacecraft rise, approximately 70 minutes after launch.

Because of the suddenness with which a launch hold was initiated and terminated, there was much confusion about the time of the actual liftoff. This confusion resulted in the required liftoff probe ephemeris tape (PET) being delivered approximately 15 minutes after liftoff. Thanks in large part to the prelaunch streamlining of procedures, predicts were available approximately 20 minutes before the expected spacecraft rise.

The accuracy of the launch phase prediction (as measured by pseudo-residuals) was very good. The pseudo-residuals were computed in near-real time by differencing radio metric data with the liftoff tracking predictions in the NOCC Tracking Real-Time Monitor (RTM). These residuals had the following average values during the early portions of the launch pass of DSS 12:

Δ hour angle $\cong$ -0.085 degrees

Δ S-band doppler $\cong$ -130 Hz (S-band)

Δ best-lock frequency $\cong$ 8.9 Hz (VCO)

An important facet in the design of an initial acquisition strategy is the effect of an abnormal launch on the spacecraft trajectory. To this end, 3σ launch trajectories were provided by the Voyager Navigation Team. Examination of these trajectories yielded the following 3σ uncertainties in the tracking parameters at the rise of DSS 12:

3σ hour angle = 0.31 degrees

3σ one-way doppler = 300 Hz (S-band)

3σ two-way doppler = 600 Hz (S-band)

3σ best-lock frequency = 182 Hz (S-band)

These figures were somewhat smaller than those encountered in other recent launch phases. For example, for the Helios 2 launch the 3σ uncertainties were:

3σ hour angle = 1.15 degrees

3σ D1 = 3500 Hz (S-band)

3σ XA = 1632 Hz (S-band)

These data were, however, somewhat incomplete in that there exist many different possibilities for nonstandard trajectories which could result in larger errors. In light of this and in order to insure complete success, the initial acquisition strategy was developed from an extremely conservative approach.

The DSN tracking procedures and, in particular, the initial acquisition procedures were conservatively designed to encompass any launch contingency. These procedures significantly contributed to the successful completion of this phase of the Voyager mission.

B. VOYAGER 2 INITIAL ACQUISITION

The initial downlink acquisition at DSS 12 proceeded very smoothly, with acquisition occurring at 15:41:31 GMT, or approximately one minute before the expected spacecraft rise time. The receiver was swept through a very wide (approximately 12 kHz) range of frequencies centered at the downlink frequency expected at spacecraft rise and commencing well before rise. The downlink frequency acquisition plan is described in more detail in Subsection II-E.

The early acquisition was due to the fact that, because of the high declination angle, spacecraft rise was dictated by the antenna mechanical limits rather than the local horizon. Thus, it was possible to "see" the spacecraft below the antenna limits. Additionally, because of the high signal levels present during this phase, it was possible to lock the receiver as the spacecraft passed though the side lobes of the acquisition antenna. This resulted in acquisition approximately 40 seconds earlier than planned.

Shortly after liftoff, an apparent problem with the spacecraft inertial reference unit gyros was detected by the project. The attitude control computer had changed gyro pairs several times. The project requested that the DSN acquire the uplink at the earliest possible time to allow for emergency commanding, if it became necessary. Since the initial uplink sweep had already been designed to start at the earliest possible time, it was decided not to depart from the current plan.

The uplink acquisition parameters provided to DSS 12 were:

(1)	Transmitter on:	15:47:40 GMT
(2)	Transmitter power:	10 kW
(3)	Frequency:	22014140.0 Hz(VCO)

(4)	Start tuning:	15:48:00 GMT
(5)	Tuning rate:	180 Hz/min (VCO)
(6)	Tune to:	22014380.0 Hz (VCO)

A comparison of the instructed sweep with the sweep actually performed at DSS 12 is shown in Figure 5-1. As can be seen, the sweep was well-performed and closely followed the expected tuning pattern. The spacecraft receiver was acquired at 15:48:36 GMT, within 10 seconds of the expected time.

The acquisition of the two-way downlink did not proceed as smoothly as that of the uplink. The receiver was quickly relocked (in about 3 seconds) to the coherent downlink. It was soon noticed that the doppler residuals were larger than expected (almost six times the 3σ magnitude) and changing very quickly.

At 15:49:57 GMT, receiver lock was broken and a sideband search performed. Upon reacquisition of the downlink, the doppler residuals showed that the receiver had again locked on to a spurious signal. This time, however, the doppler residuals indicated a positive bias but with the same magnitude as those calculated before the sideband search. Additionally, the signal was very noisy with doppler noise averaging more than 11 Hz.

At approximately 16:00:00 GMT, DSS 12 was instructed to perform yet another sideband search. During this search, the receiver was swept through a frequency range of approximately 170 kHz (S-band level) around the expected carrier. When the receiver was relocked at 16:00:30 GMT, the carrier was finally acquired, as indicated by a doppler residual of approximately -130 Hz and doppler noise of approximately 0.030 Hz.

The cause of the spurious signals has not been precisely determined. However, it is believed that since (1) no other station experienced the same problem, (2) the spurious signals were spaced evenly (approximately 4 kHz) on both sides of the expected carrier frequency, and (3) the station reported that they returned to the original frequency after the sideband search, the spurious signals may have been an artifact of the effect of the high signal level on the DSS 12 receiver.

In accordance with the plan, tracking predictions based on the actual liftoff time were generated and transmitted to DSS 12 prior to the expected spacecraft rise time. These predictions were in turn used in the generation of the antenna drive tape used by DSS 12 during the early portion of its pass.

At 15:49:27 GMT, immediately following the completion of the two-way acquisition, DSS 12 went to autotrack. However, partly because of the receiver lock on the erroneous frequency, the antenna quickly drifted off point, driving a maximum of two degrees from the predicted pointing angle. At 15:49:57 GMT, DSS 12 returned to aided track.

After locking to the carrier, the drive mode was returned to autotrack successfully at 16:02:21 GMT.

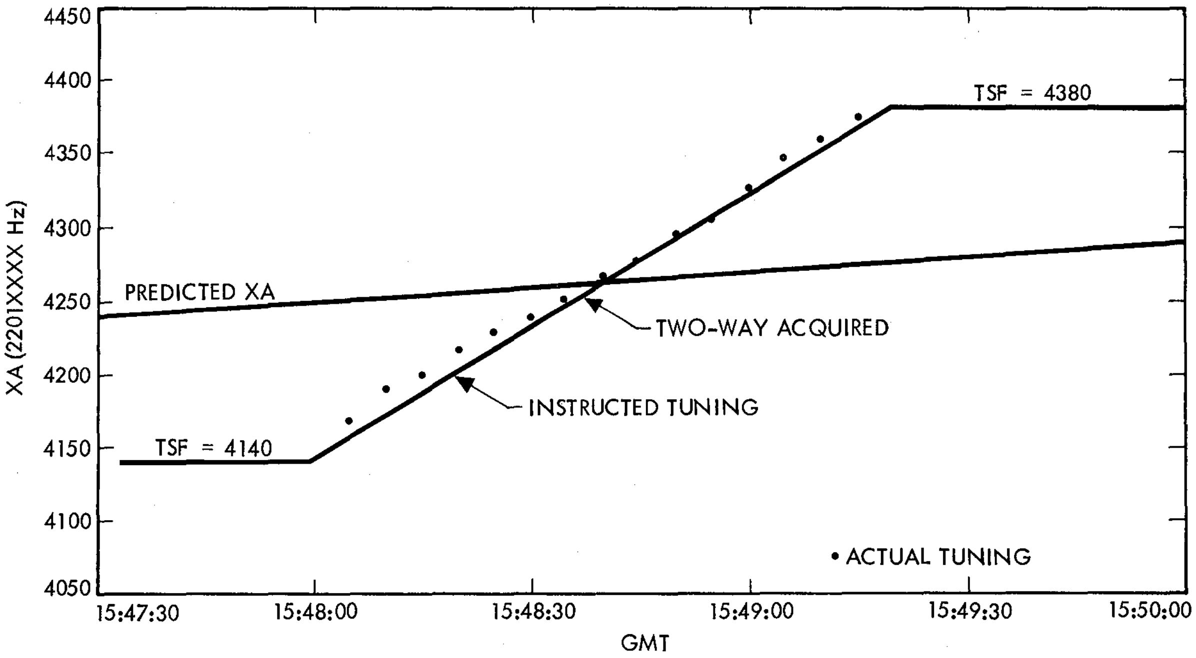

Figure 5-1. Comparison of Actual Versus Instructed Tuning at DSS 12 for Voyager 2 Launch

Because of a change in the attitude of the spacecraft, DSS 12 returned to aided track shortly after 17:11:00 GMT, when the signal level fell below the autotrack threshold. The station continued to track in this mode for the remainder of the pass.

Range data collection for Voyager was to begin shortly after the initial acquisition at DSS 12. Additionally, plans were made to transfer the uplink from DSS 12 to DSS 14 so that ranging could continue for as long as possible.

Originally, it had been planned that the ranging would be done with 18 component acquisitions interspersed with 10 component acquisitions. Risks inherent in changing range parameters (i.e., possibly significant losses of data) were pointed out to the Voyager project. It was decided by the project to pipeline 15 component ranging acquisitions separated by three differenced range versus integrated doppler (DRVID) measurements.

The following parameters were to be used:

(1) T1 = 59 seconds

(2) T2 = 2 seconds

(3) T3 = 60 seconds

(4) TO = 3CCEE (the ranging code)

(5) Round-trip light time (RTLT) = 0 seconds

(6) Number of components = 15

(7) Carrier Suppression = 3 dB.

Ranging data at DSS 12 were found to be invalid shortly after the ranging sequence was started. Several unsuccessful attempts were made to locate and correct the problem, but no obvious problem could be found during the pass.

Later, extensive investigation revealed that the fault was in the rate-aiding circuitry of the Planetary Ranging Assembly and was therefore not detectable in the testing configuration used during the initial Voyager 2 pass.

The loss in ranging data from DSS 12 was somewhat compensated for by the short period of ranging at DSS 14.

DSS 14 became the first 64-meter station to acquire the Voyager spacecraft at 15:41:52 GMT, within 20 seconds of the acquisition by DSS 12. The ease of the lockup allayed fears that, because of the narrow beamwidth of the antenna and the large uncertainties in the near-earth trajectory, DSS 14 would not acquire in time to receive the high-rate (7.2 kb/s) telemetry data.

On the first launch (Voyager 2), DSS 14 was prime for the 7.2 kb/s telemetry data, which was transmitted by the spacecraft shortly after initial acquisition. Due to an error in entering the correct Subcarrier Demodulator Assembly (SDA) frequency during the generation of the tracking predictions sent to the station, DSS 14 was 25 minutes late in acquiring valid telemetry data. There would have been a loss of data if MIL 71 had not acquired the 7.2 kb/s data on time and made it available to the Voyager project.

MIL 71 again came to the rescue, when at 16:38:00 GMT (same day) the spacecraft failed to acquire the sun, and went into the failure recovery mode, switching data rates from 7.2 kb/s to 40 b/s. MIL 71 immediately detected this change, locked up on the data, and alerted the network. All stations responded quickly and data outage was negligible.

Following the transfer of the uplink from DSS 12, DSS 14 began ranging at 19:47:00 GMT. The ranging data were good and provided the project with important near-earth data. DSS 14 continued tracking until 22:05:00 GMT.

C. VOYAGER 1 INITIAL ACQUISITION

Upon launch of Voyager 1, DSS 11 acquired the spacecraft about 2 minutes before DSS 14 and DSS 12. Since DSS 11 (not an MDS station) data were record-only, the project chose to process DSS 14's telemetry as prime from Goldstone. Telemetry from DSS 14 continued without problems until loss of signal (LOS). DSS 12 experienced some difficulty reacquiring the spacecraft downlink after going two-way. The difficulty was caused by a 12 Hz filter failure. Overall, the initial acquisition of Voyager 1 went very smoothly. Only minor problems occurred and had no effect on the delivery of data to the project.

SECTION VI

EARTH-JUPITER CRUISE SUPPORT

A. INTRODUCTION

The Earth-Jupiter cruise began with the first acquisition of the Voyager 2 spacecraft by the overseas Deep Space Communication Complexes of Australia and Spain.

The interplanetary cruise activities gathered data on the field and particles environment of the solar system as the spacecraft moved away from the sun. In addition, the pointing and stabilization capability of the spacecraft allowed detailed observations of targets of opportunity that included nebulae, asteroids, and stars that had not been possible to view on previous outer planetary missions.

The second launched spacecraft (Voyager 1) arrived first at Jupiter with closest approach occurring on 5 March 1979, at about five Jupiter radii. The second arriving spacecraft (Voyager 2) had its closest approach to Jupiter on 9 July 1979, at about 10 Jupiter radii.

As an indication of the high-level support provided by the DSN tracking stations and the Network Operations Control Team, during selected periods of the cruise phase from 20 November through 31 December 1978, there were 170 scheduled Voyager tracks. The average track was between 8-1/2 and 9 hours long, resulting in approximately 1488 tracking hours for that time period. Of these tracks, 111, or 65 percent, were trouble-free. Of the 59 remaining passes that had problems, 12 passes concerned a Command Processor Assembly (CPA) alarm that caused no loss of data. This essentially meant that 123 or 72 percent of the passes were trouble-free relative to data loss. Of the 47 remaining tracks, the problems were primarily high-speed or wideband data line outages. The 39 remaining passes resulted in nonreceipt of 23 hours and 27 minutes of real-time data. Five hours and eight minutes of this data was radio metric or ranging data and nonrecoverable; the remaining 18 hour's and 19 minutes of telemetry data and the nonreceipt caused by the communication problems were recoverable, requiring only data recall from the stations to complete the required data records. Overall, 98.3 percent of the data was received in real-time, with only 0.3 percent of the doppler and ranging data being nonrecoverable and all of the telemetry data being recoverable.

Intermediate Data Records (IDRs) were provided on each pass. The DSN commitment of at least 96 percent was exceeded, usually averaging approximately 99.6 percent of all data received.

Two of the most significant Command System failures were software-related and were eventually corrected with a new Command Processor Assembly software version. These were loss of response from a station CPA, because the CPA Temporary Original Data Record (TODR) would write past its partitioned space, destroying a portion of the CPA program, and random inability to access either CPA, caused by a software anomaly in the CPA timing.

These 170 scheduled tracks required a minimum of 13 DSN personnel throughout the system per pass for support. Since each track averaged 8.75 hours in length and 13 support personnel, a total of 19,338 man-hours was expended for the period. Considering the nonreceipt in real-time of 23.45 hours (23 hours and 27 minutes) of data, for the 19,338 man-hours, a 0.12 percent error or nonreceipt rate results. Likewise, the 23.45 hours of data nonreceipt for 1488 tracking hours results in a 1.58 percent non-real-time data reception due to equipment problems. The 5.133 hours (5 hours and 8 minutes) of radio metric data loss in the 1488 tracking hours equals 0.34 percent of nonrecoverable data due to misconfigurations or human problems. Further, the 5.133 hours of data loss for 19,338 man-hours expended is a 0.026 percent error rate. This error rate is considered negligible in relationship to the number of tasks performed, i.e., computer loading, knob turning, computer instruction inputs, interpretation of required configuration, scheduling codes, short turnarounds, etc., to complete a tracking pass.

B. SPECIAL PROCEDURES

There were a number of special procedures that have been documented to support the cruise phase of the Voyager Mission. This section includes all known special procedures required to support cruise and encounter operations. The individual procedures specify whether it is applicable to Voyager 1, Voyager 2, or both Voyager spacecraft.

1. Tracking Voyager 2 at High Elevation Angles

The inclination of the Voyager 2 spacecraft was such that it was at high elevation angles when tracked by the northern hemisphere stations. The high elevation angles did not cause any problems for the 34-meter DSSs, but 64-meter DSSs experienced tracking outages when the elevation angle exceeded 88.0 degrees.

The upper elevation tracking limitation at the 64-meter stations was 88.0 degrees. When elevation reached 88.0 degrees, it was necessary to break track, rotate azimuth 80 to 180 degrees, and resume track. When the 64-meter stations experienced this keyhole effect, up to 20 minutes of data outage occurred.

The procedure to break track and rotate the antenna was coordinated in advance and concurred with by Network Operations Chief (NOC). The time and azimuth angles to break (and to resume) track were either in the sequence of events (SOE) for the pass in question or were provided by the NOC. This procedure was applicable during the early portion of the Voyager Mission.

2. Radio Frequency Subsystem Tracking Loop Capacitor (RFSTLC) Test

This test was designed to check the status of a 75 microfarad capacitor of the spacecraft flight receiver. The capacitor was tested by measuring the time constant of the circuit. This was done by tuning the uplink frequency to offset the receiver VCO, dropping the uplink, and monitoring the VCO1 static phase error as it drifts back to its rest frequency.

This test results in a healing effect on the failure mechanism. As the SPE voltage was increased across the capacitor plates (with VCO frequency offset), the potential vaporized impinging particles and prevented the short from occurring at those particular points.

The plan for Voyager was to perform this test weekly on the active receiver of Voyager 1. This action should be posted in the project SOE as RFSTLC and may be conducted over any DSS supporting Voyager.

3. Voyager Spacecraft Command Detector Unit Signal-to-Noise Ratio Test (CDU SNR Test)

This procedure applied to both Voyager 1 and Voyager 2. The CDU SNR test, which was part of a periodic engineering and science calibration (PESCAL), was normally performed on each spacecraft on a biweekly basis. The CDU SNR test was initiated by commands contained in the spacecraft onboard Computer Command Subsystem (CCS) load.

In order to conduct the test, the spacecraft CDU must be maintained in continuous bit-sync lock for the period of the test. The DSN must transmit command subcarrier and bit-sync continuously with no command data. This capability was provided in the form of a special Voyager command standards and limits table entitled "PESCAL," which was entered by Network Analysis Team Command (NAT CMD) at the appropriate time. This table sets up Manchester Coding at 16 Hz squarewave to provide bit-sync when in the IDLE-2 mode.

4. Near-Simultaneous Ranging (NSR) Transfers

A unique geometry, zero declination, existed at Saturn encounter for Voyager 2. This geometry made it impossible to solve for the spacecraft's declination by fitting doppler data as is normally done in the orbit determination process. An alternative technique for deriving the spacecraft's declination was by use of range data taken nearly simultaneously from stations at widely separated latitudes and triangulating to solve for the needed declination angle. This dependence upon range data required that highly accurate range measurements and range delay calibration information be available to the navigators and radio scientists.

5. USO Frequency Calibrations

The purpose of the ultrastable oscillator (USO) Frequency Measurement Test is to periodically measure the absolute frequency and short-term stability of the USO. This was accomplished by acquiring the downlink in the one-way mode for a period of one hour and recording the doppler at a rate of one sample every one second. The Voyager project reduced the doppler data to determine frequency stability.

6. Voyager Radio Frequency Subsystem Tracking Loop Capacitor Offset (RFSTLCO)

This procedure was implemented by the Voyager project upon detection of radio frequency subsystem (RFS) loop capacitor degradation. In order for the DSN to respond quickly to a project request (i.e., within 24 to 48 hours), a contingency procedure was necessary; the intent of this procedure was to meet that need.

The prime purpose for offset tracking (stressing the spacecraft receiver loop ±65 kHz at S-band) was to further retard loop capacitor degradation or possibly effect a loop capacitor healing condition. The 65 kHz offset provides a voltage across the capacitor plates. The voltage potential vaporizes impinging particles and prevents further loop capacitor degradation.

7. Voyager Antenna and Sun Sensor Calibration (ASCAL)

The high-gain antenna (HGA) calibration and sun sensor calibration sequence is called ASCAL (antenna and sun sensor calibration) and combines both calibrations in one sequence. The following sequence descriptions were provided to show spacecraft events and signatures to be expected during ASCAL.

The sequence basically involves performing a spacecraft ±3 degree maneuver in the yaw axis followed by a ±3 degree maneuver in the pitch axis. The resulting variations in the downlink S-band and X-band carrier levels were then used to calibrate the HGA pointing error and were correlated with variations in Sun sensor error signals to calibrate the sun sensor. Since a bias of 3 degrees in the HGA pointing coincides almost exactly with the first null of the S-band HGA pattern, it was possible for the S-band downlink to drop lock during this sequence. Typical S-band downlink variations were about 25 dB. Since it was also possible for the uplink to drop lock, the sequence was run in the two-way, noncoherent (TWNC) mode. This insured the downlink would remain on the USO frequency regardless of the uplink status.

8. Special Procedure for Voyager 2 Manual Uplink Tuning

The shorted VCO loop filter capacitor had greatly reduced the Voyager 2 spacecraft receiver's ability to track the uplink signal. The operational passband was about 200 Hz (±100 Hz). The doppler due to earth rotation caused the uplink signal to sweep through the passband. The amount of time that the spacecraft receiver saw the uplink depended upon where in the track the spacecraft receiver first acquired the uplink signal. The in-lock time was about 40 minutes at midtrack, about two hours at the beginning of the track, and about one hour 15 minutes near the end of the track.

Using a doppler ramping technique, stations maintained two-way lock for the entire track, provided that the spacecraft receiver frequency remained generally stable. The doppler ramping technique used a series of doppler ramps, of a specific rate, to vary the uplink as required to keep the uplink signal within the spacecraft receiver passband.

9. Special Procedure for Voyager 2 Two- or Three-Way Acquisitions and Station Transfers

The normal two- or three-way acquisition and transfer procedures used when tracking Voyager 1 were not adequate for Voyager 2. Because of the failed Voyager 2 receiver VCO loop, different procedures were required.

The normal uplink procedures were not used for Voyager 2, because the receiver VCO loop capacitor had failed, disabling its ability to track the received signal. The spacecraft receiver had a usable passband of ±100 Hz. The signal was kept within this passband to achieve or maintain spacecraft receiver lock. The only reasonable method for keeping the signal within this narrow passband was to ramp the uplink to compensate for any doppler shift.

10. Special Procedure for Voyager 2 with New MDA Software

A new OP-F version of the MDA software program was provided for computer control of the exciter controller uplink tuning for Voyager 2. All changes in ramp rate or status caused the MDA to issue a block of programmed frequency data (DT-42). In order for the NOCT to monitor the status of uplink ramping, the MDA was placed in the RUN mode with the high-speed data interface enabled prior to enabling the MDA Programmed Oscillator Control Assembly (POCA) or DCO interface or requesting uplink predicts. The NOCT provided the DSS with a bias so that ramping predicts could be corrected using the frequency offset operator control input (OCI).

11. Special Procedure for RFS AGC Test

The spacecraft radio frequency subsystem (RFS) automatic gain control (AGC) test provided a means for measuring the spacecraft receiver threshold and AGC characteristics. The spacecraft AGC was measured during the spacecraft compatibility test period at CTA 21 prior to launch. This test provided data that was compared against the MIL 71 prelaunch data and used for current evaluation of spacecraft receivers.

Basically, the procedure of this test was to reduce the uplink power until the spacecraft receiver threshold was reached. The plan for achieving this was as follows:

(1) Reduce uplink power in two steps of 10 dB each, using the range modulator, for total power reduction of 20 dB.

(2) At this point, the uplink carrier power was reduced 20 dB.

(3) The final 10 dB to reach Voyager 1 receiver threshold was obtained by reducing the transmitter power in steps until spacecraft receiver threshold was reached.

12. General Procedure for X-Band Receiver Acquisition

During the Voyager cruise phase, the spacecraft was normally in the wide deadband mode. When the spacecraft was in this mode, the X-band signal varied from nominal signal level to receiver threshold during the mode cycle. Ground antenna conical scanning (CONSCAN) was not possible when in this mode, and normally X-band data were degraded and not required by the Voyager project.

When the Voyager project needed to receive good X-band data, the spacecraft medium deadband mode was selected. In the medium deadband mode, the signal level varies from nominal to about 3 dB below nominal during the mode cycle. Ground antenna CONSCAN was required for the medium and narrow deadbands. When the project considered the data to be critical, it selected the spacecraft narrow deadband mode since it provided optimum data quality.

13. Special Procedure for Voyager Delta Differential One-Way Ranging

The Voyager delta differential one-way ranging (delta DOR) provided an independent source of spacecraft declination data to validate the Voyager near-simultaneous ranging data for Saturn encounter. The observables for this measurement were the sidebands of the spacecraft downlink S-band radio frequency signal and a nearby quasar. The unmodulated sidebands of the Voyager high-rate telemetry subcarrier (360 kHz) were employed. Voyager's differenced right ascension and declination with respect to the quasar were determined with observations on two baselines. Typical measurement times were 25 minutes per baseline. Ten minutes of data were taken on the spacecraft's unmodulated sideband signals, and ten minutes of data were taken on the quasar, with 5 minutes for antenna move times. Spacecraft-to-quasar angular separation in the sky was less than 10 degrees.

C. DSN SPECIAL ACTIVITY

An MDA software package which provides a new radio metric data format capability, TRK 2-14, was distributed to the field on 27 February 1978. This format was basic to the new interface for radio metric data to the project. The new interface was between the DSN and the project in the form of an Intermediate Data Record (IDR) and replaced the Mission Control and Computing Center (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 were not processed in real-time by MCCC.

A series of training and/or 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 were generated to alleviate the problems. On 1 May 1978, support of Voyager 1 was converted to the new interface, and on 6 May 1978, 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 15 January 1978. The installation and subsystem testing were completed on 22 March 1978. On 23 March 1978, the Operational Verification Tests (OVTs) were initiated. The minor problems encountered during these tests were corrected, and DSN Engineering Interface Verification Tests (DEIVTs) were conducted on 3 and 6 April 1978. The Performance Demonstration Test (PDT) was conducted on 11 April 1978, and the Ground Data System (GDS) Test on 17 April 1978. The GDS test was only partially successful and was rerun on 12 May 1978. 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 26 April 1978 and assumed its project support role along with the other 26-meter stations.

A new digital DSS Radio Science Subsystem (DRS) was implemented at the 64-meter subnet to replace the analog method of recording radio science data. This new DRS was implemented in different phases as new equipment became available. Basically, the subsystem has a narrowband (prime) and wideband (backup) capability.

The phase one subsystem implemented at DSSs 14 and 43 (until the narrowband multimission receiver became available) utilized an S- and X-band open-loop receiver (OLR) (for narrowband) with the following filter bandwidth selection:

S-Band	X-Band
1 kHz	3 kHz
2 kHz	7.5 kHz
5 kHz	15 kHz
10 kHz	30 kHz

The OLR output was fed to the Occultation Data Assembly (ODA) analog-to-digital (A-D) converters and Modcomp computer) for digital tape recording at sample rates of 2K, 5K, 10K, and 20K samples/s.

The wideband backup system utilized a wideband (1 MHz) Multimission Receiver (MMR) which was recorded on a Digital Recorder Assembly (DRA) in the megabit range.

To facilitate onsite observations of the digital recordings (since the data were usually mailed to JPL for data reduction), a new Spectral Signal Indicator (SSI) was used to verify proper operation of the system during recording.

The ODA received Radio Science predicts from JPL to drive the narrow-band OLR programmable local oscillator to maintain the spacecraft downlink signal within the desired OLR filter bandwidth. These predicts were a series of linear ramps which profiled the anticipated doppler signature from the spacecraft.

The Madrid (Spain) 64-meter station Radio Science Subsystem basically used the same system described above except the wideband system used the 300 kHz output of the OLR and the narrow-band system used the new narrow-band MMR (7 filters, S- and X-band). The new narrow-band MMR was available at DSS 14 for Voyager 2 Jupiter encounter.

In the continuing effort to provide calibration data for the Tracking System, in both the S- and X-band frequencies, the implementation of a meteorological atmospheric sampling capability was effected at the 64-meter stations.

The primary data provided are temperature, barometric pressure, dew point, water vapor partial pressure, precipitation, precipitation rate, diurnal Faraday rotation, Faraday rotation, Faraday rotation angle, satellite azimuth, satellite elevation, solar insolation, microwave polarization angle, ellipticity, and microwave mode. The initial capability was provided by an HP9821A calculator recording data on a seven-track recorder. The collected data were transmitted to JPL once a week, utilizing the station Digital Instrumentation Assembly (DIS). An IDR was made from the received data and turned over to the Tracking System Analytical Calibration (TSAC) operation for further processing. The processed data were then available for navigational orbit determination operations.

The complexity of the Voyager Mission and the effort to reduce the actual real-time operation of the commanding effort placed a requirement on the DSN to revise its Command System. The change at the DSSs to separate Command and Telemetry computers and the change of the MCCC from the IBM 360/75 computer to the Modcomp minicomputers (Mark III System) allowed a complete change in concept.

The DSS Telemetry and Command Processors (TCPs) were replaced by a Command Processor Assembly (CPA) and a Telemetry Processor Assembly (TPA) as separate computers. The CPA was provided with capabilities of the TCP with an alternate capability (store-and-forward mode) of storage space for eight files, each file capable of 256 elements (commands) for a total storage of 2048 commands. This total capacity could be used at any one time (or part of it could be used) resulting in a greater flexibility in the Command System operation. The command files could be assigned a transmit time to be consistent with a command window or with any opportune time during a spacecraft tracking pass by the Voyager Project. Checks for errors, computer handshaking, and status reporting were expanded to provide a complete, more or less automatic, Command System.

Under the operation with the DSS Telemetry and Command Processor and the MCCC 360/75 computers, only 24 commands could be stored at the station in four command modules, each with six commands in queue. During operations, after one module of commands was transmitted, another module was promoted in the stack, and the empty module refilled. This procedure required constant operator attention and intervention during long command loads.

Concurrent with the Command System change, the Telemetry System was also changed. Again, the DSS was provided with a separate telemetry computer as was the MCCC. In preparation for the Voyager encounters, a capability was also provided at the 64-meter and 34-meter stations to interface with wideband data lines to support the data rates expected from the spacecraft.

DSSs 14 and 63 were provided with the capability to return, in real-time, all of the high-rate telemetry up to and including the 115.2 kb/s imaging and general science data. DSSs 12 and 43 were provided with the capability to return, in real-time, all of the high-rate data up to and including the 44.8 kb/s imaging and playback data.

The limitation of the real-time capability at DSS 12, and especially at DSS 43 for high-rate telemetry data return, made it mandatory that a strategy be developed to return high-rate telemetry data received at the higher data rates in near-real time. The procedure developed was to record the higher rate telemetry data and, after one tape was completed, start the replay of the data on the TPA over the 56 kb/s line at line rate while continuing to record on the other TPA. Since this method required a longer transmission time as compared to receive time, the replay continued postpass into the next tracking period. To implement this requirement necessitated negotiations and understandings with the Pioneer Venus and Viking Projects.

DSS 12 was decommitted from project support in June 1978. The station was converted from a 26-meter antenna S-band station to a 34-meter antenna S- and X-band station during the period June through September 1978. Subsystem and system tests were conducted at the station by station and implementation personnel during October 1978. The station was available for DSN testing, training, and demonstration tracking capability during November 1978. This required a program for all station personnel to become familiar with the new capability; therefore, support periods were scheduled so that each crew was exercised at least twice. The DSN activities included 11 OVTs conducted by the Network Operations Project Engineers (NOPEs), each approximately eight hours in duration and supported by a minimum of 13 DSN operational personnel. This program required 88 station-hours and 1144 man-hours. The subsystem and system testing took a week longer than scheduled, but the DSN activities schedule was condensed and the station was verified for operational support on schedule.

Upgrade of the initial system provided for nine-track recorders instead of the seven-track recorders. This brought the facility in line with other station recorders and the normal interface with the station CMF for data transmission.

During the Jupiter near-encounter phase of the Voyager 2 Mission, telemetry signals from DSSs 12 and 14 were combined to demonstrate the antenna array configuration. This configuration was required for the Saturn encounter phase of the Voyager Mission at all three Complexes. The main objective for antenna arraying was to provide an effective signal increase of approximately 1.2 dB on the X-band signal during Saturn encounter.

The antenna arraying was tested and readied for the configuration demonstration at DSSs 12 and 14. The arraying consisted of both DSSs 12 and 14 tracking the spacecraft simultaneously. The telemetry data was microwaved from DSS 12 and input to the real-time signal combiner with the signal from DSS 14. The combined output was transmitted to JPL.

The precision of the Planetary Ranging Assembly (PRA) range data was questionable since adequate capabilities to verify the accuracy were not readily available. The decision was made to install the MU2 ranging system at the DSS 42/43 conjoint station and conduct tests that allowed data comparison.

The MU2 equipment was shipped to DSS 42/43 and installed in October 1978. Data-gathering passes were authorized and the data evaluated. Reports in December 1978 indicated that the MU2's higher code frequency (1 MHz) and filtering had dramatically reduced residual scatter. Preliminary results indicated a three-fold increase in range precision (from approximately 6 meters to approximately 2 meters). The MU2 continued to be used for tests during December, and plans included utilizing the equipment for investigation of an interstation range bias problem.

In preparation for the encounter phase, it was necessary that maximum antenna gain be available. To optimize the antenna gain, it was necessary to refocus the subreflector whenever the antenna elevation was below 40 degrees elevation. Three focus settings at 10, 30, and 50 degrees elevation were used. The X-band Subreflector Controller (SRC) required calibration every four months. Settings established during the calibrations were used on a daily basis or as required to optimize antenna gain. When refocusing, the stations extract the elevation angle from the DSN predicts.

The subreflector refocusing test conducted with DSS 14 on 1 December 1978 was very successful and showed that there was no effect on radio metric or radio science data during refocusing periods.

D. VOYAGER 1

From the moment of launch, the Voyager spacecraft were under alternating surveillance by a worldwide tracking and data system which included elements of the NASA JPL Deep Space Network, the Air Force Eastern Test Range (AFETR), and the NASA Spaceflight Tracking and Data Network (STDN).

Voyager 1 completed its first trajectory correction maneuver (TCM) in two parts on 11 and 13 September 1977. An analysis of the TCM data indicated a 20 percent undervelocity resulting from each part of the maneuver. The suspected cause was impingement of the thruster exhaust on the spacecraft structural support struts. The ungained velocity was planned to be compensated for during the next scheduled TCM. The maneuver was considered successful and included calibration sequences of the dual frequency communications links and the high-gain antenna S- and X-bands. During these sequences, the 3.7-meter (12-foot) diameter high-gain antenna dish was pointed towards earth and the S-band and X-band radio links were calibrated over DSS 14.

These periodic flight path adjustments were necessary to assure precise arrival times of the spacecraft at their objectives, maximizing science data return. As a result of the trajectory adjustment, Voyager 1 arrived (closest approach) at Jupiter 5 March 1979, studying the interactive region between Jupiter and its satellite Io.

The spacecraft began its Earth-Jupiter cruise phase on 15 September 1977 having completed all planned near-earth activities.

A recorded earth-moon video and optical navigation data sequence was conducted on 18 September 1977 in which dramatic pictures of the earth and moon were recorded by the spacecraft 11.66 million kilometers (7.25 million miles) from earth. The video playbacks of these pictures were conducted on 7 and 10 October 1977.

The second trajectory correction maneuver was executed on 29 October 1977. The maneuver was successful, with pointing accuracies and undervelocity resulting during the first trajectory maneuver on 11 and 13 September 1977 being accounted for in the sequence.

On 13 December 1977 Voyager 1 conducted a fairly extensive mapping of the Orion nebula with the ultraviolet spectrometer (UVS) and photopolarimeter (PPS) instruments.

Voyager 1, on 15 December 1977, earned its title when it took over the lead from Voyager 2 and was now farther away from the earth and sun. Voyager 1 was in Earth-Jupiter cruise with all subsystems and experiments in good working condition.

Both spacecraft were in the cruise phase of their Earth-Jupiter trajectories. This phase was planned to be relatively quiet and routine, broken by an occasional spacecraft maneuver or special calibration procedure. However, support activities were anything but routine. Spacecraft anomalies dictated real-time commands, and there were special maneuvers, calibration sequences, and tests not originally planned for the cruise phase. The DSN responded in real-time to satisfy all project requirements where resources were available. Additionally, special tests and procedures to support these tests and calibration sequences were developed and implemented.

The Voyager and Helios Projects took advantage of an alignment of their respective spacecraft and the earth, which during the period between 15 October and late December 1977 provided unique data on solar-related field and particle phenomena. To augment data acquisition in this interval, the Weilheim 30-meter tracking station under the direction of the German Space Operations Center (GSOC) tracked the Voyager spacecraft. In order for the Weilheim station to track the Voyager spacecraft, the DSN provided tracking predicts (state vectors) and a communications decoder for interfacing with the NASCOM high-speed data lines. Several successful tests were run and, as a result, the first live track of the Voyager spacecraft by the Weilheim station was conducted during the week of 17 October 1977.

Weilheim continued to gather the Voyager spacecraft data until 31 December 1977, when support was terminated due to the passing of the radial alignment period. A spiral alignment of the two spacecraft occurred in April 1978, and Weilheim again tracked the Voyager 1 spacecraft.

On 29 December 1977, a negative 360-degree roll turn with Voyager 1 was successfully supported by DSS 63. The objective of the test was to determine the offset between the HGA electrical boresight and that of the turn axis. Preliminary analysis of the data provided by DSS 63 indicated an offset of 0.15 to 0.2 degrees existed (which was within the design tolerance).

All critical mission activities such as TCMs, celestial reference changes, cruise science maneuvers, special calibrations, and spacecraft emergencies required accurate telemetry link predictions to guarantee any measure of success. The telecommunications links were accurately predicted in most all instances by both the DSN and project spacecraft and telecommunication teams. These have greatly influenced the successful support provided by the DSN in all such critical mission phases.

S-band link residuals through December 1977 showed that downlink AGC values for both spacecraft were near nominal while symbol signal-to-noise ratios (SNRs) were about +2 dB.

Due to spacecraft anomalies and additional instrument calibration requirements, more spacecraft commands were sent to date than originally planned prior to launch. A total of 11,255 commands were transmitted to Voyager 1 by the end of December 1977. During the cruise mission phase, a command load was planned about once a month; however, actual activities were close to weekly, plus there was real-time commanding to meet real-time situations.

Voyager 1 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 at a velocity of approximately 19.9 kilometers (12.4 miles) per second relative to the sun, with a one-way communication time of 30 minutes and 45 seconds.

On 17 February 1978, 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 acquire Canopus, and the HGA was automatically selected. A programmed 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 degrees 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-degree turn error represents a deviation in scale factor values from the design value of approximately 0.37 percent, 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 were corrected by including the appropriate value for each gyro in the generation program.

On 17 February 1978, 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 was performed in March and April, as was a reset diagnostic test. There appeared to be a threshold on positive ion measurement, causing the output data to be shifted such that only the peaks of the plasma curve appeared.

The loss of sensitivity of the main plasma detector was diagnosed and simulated in the laboratory. The problem was an open circuit in the feedback loop of an amplifier driving the buckout grid of the forward detector cluster. A procedure of temperature cycling was initiated, and the instrument recovered completely on 8 May 1978.

During a calibration of the scan platform on 23 February 1978, 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 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 17 March 1978, 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 24 through 30 March 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 continued with a plan to define scan platform pointing region limitations.

On 18 May 1978, the gyros were turned on by an onboard sequence for calibrations to be performed on 19 May 1978. During the gyroscope calibration (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 26 May 1978 and use this opportunity to obtain long-term gyro drift data.

A low-energy charged particle subsystem (LECP) sun interference test was performed on 23 May 1978 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.

Continued scan platform slewing tests did not result in any difficulties as encountered in February 1978, and constraints on the scan platform slewing envelope were removed. The suspected cause was debris in the gears, which was apparently crushed. No further difficulty was detected.

Superior conjunction occurred during July 1978. Voyager 1 entered a sun-earth-probe (SEP) angle of 5 degrees inbound on 6 July 1978 and a SEP angle of 5 degrees outbound on 21 July 1978. The minimum angle was 0.75 degrees. S-band AGC and SNR degradations were observed and correlated with the degradations recorded during the Mariner 69 superior conjunction.

E. VOYAGER 2

Because of the high declination (41 degrees) of the Voyager 2 trajectory, it was found that DSS 62 would be unable to acquire the spacecraft downlink until the spacecraft reached an elevation of approximately 16 degrees, this being the minimum elevation at which the antenna could be pointed at this declination. On the first pass, this constraint caused more than a 50-minute gap between the end of track at DSS 44 and the start of track at DSS 62. However, because of the strong signal levels expected during that time, it was possible to narrow the gap considerably using the SAA. From available information, the threshold of the SAA was computed to be -164.4 dBm in the 48 Hz RF bandwidth and -170.4 dBm in the 12 Hz RF bandwidth.

The signal level at the time of DSS 44 set was expected to be at least -161.4 dBm. Thus, there would be from 3 to 9 decibels of downlink margin. From antenna patterns, it was found that the angular offsets necessary to reduce the signal level to threshold were 8 degrees for threshold in the 48 Hz RF bandwidth and 15 degrees for threshold in the 12 Hz RF bandwidth.

These offsets translated (assuming sidereal angle rates) to an increase of from 32 to 61 minutes in the view period of DSS 62. Thus, the obvious conclusion was that, by judicious use of the receiver, the downlink could be acquired using the broad (16 degrees) beam of the SAA, and at a much lower elevation than that at which the main antenna could even point, thereby reducing the gap in the tracking of the spacecraft.

It was decided to attempt to close the downlink gap (the gap in the uplink would be tolerated) using the following procedure:

(1) Two sets of predicts would be generated for DSS 62. One set, to be used for driving the antenna, would have the actual horizon mask. The other set would be used to compute frequencies for the SAA receiver sweep.

(2) DSS 62 would drive to the specified rise point (as defined by the antenna limits) at least by the time that the spacecraft would reach zero degrees elevation.

(3) At the time of the earliest possible acquisition, DSS 62 personnel would slowly sweep the receiver in the 12 Hz RF bandwidth and attempt to acquire the downlink.

(4) When the spacecraft reached the rise point, the S-band Cassegrain Monopulse (SCM) receiver would be locked, and normal tracking, including an uplink acquisition, would begin.

The coverage gap continued for several weeks after launch, but, unfortunately, because of signal level constraints, this use of the SAA would be restricted to the first pass.

The attempt to close the downlink gap between DSS 44 and DSS 62 by using the SAA met with only marginal success. During the Titan burn, the spacecraft switched to its secondary attitude control processor. Because of this unexpected change, the project decided to delay the acquisition of the stellar reference, Canopus, until the contents of the processor were examined. This decision left the spacecraft in a less-than-optimum attitude. The resultant degradation in signal level severely impacted the "off point" tracking scheme.

The antenna at DSS 62 was driven to the antenna mechanical prelimits well before the expected time of spacecraft rise. At 22:57:00 GMT, approximately five minutes earlier than expected, the downlink signal was detected, but at too low a level to maintain receiver lock. Continuous receiver lock was finally achieved at 23:27:00 GMT, but at a signal level (-170 dBm) well below telemetry threshold. At the time of continuous receiver lock, the spacecraft was still 9 degrees away from the main beam of the SCM antenna. Because of the unfavorable attitude of the spacecraft, telemetry was not received until the SCM receiver could be locked at 00:02:00 GMT.

It was apparent, then, that had the spacecraft been aligned as planned, the SAA could have been successfully used to close the gap between DSS 44 and DSS 62.

On 26 August 1977, the spacecraft was programmed to execute a pitch turn and simultaneously jettison the dust cover on the infrared interferometer spectrometer (IRIS) in hopes that enough jolt would be provided to open the boom hinge and cause the locking pin to drop into position. However, the sequence was aborted by the spacecraft before the events could take place. (The spacecraft was programmed to think such a maneuver was an emergency and to safe itself, aborting the maneuver.) It was still not certain that the science boom aboard Voyager 2 was latched, but data indicates that the hinge is only fractions of a degree away from being locked and should present no problems in maneuvering the scan platform.

The boom was stiff enough to prevent wobbling when the scan platform, perched at its tip, was maneuvered, and should stiffen further as the spacecraft travels farther from the sun into the colder regions of deep space.

Shortly after separation of the spacecraft booster motor from the bus, the spacecraft experienced what was later to be known as "a bump in the night," an erratic gyration of the spacecraft. It was first thought that the spacecraft's separated rocket motor was possibly traveling alongside and "bumping" the spacecraft. But after sifting through puzzling launch data recorded by Voyager 2, the controllers concluded that the gyrations were caused by the spacecraft's attitude stabilizing system. The system stabilized itself and remained in stable condition.

Voyager 2 was then in interplanetary cruise and, on September 2, was "put to bed" to allow flight controllers to concentrate on the launch activities of Voyager 1. The computer program was placed in a "housekeeping" sequence designed to automate the craft until September 20. In this condition, various measurements were taken during this period and tape recorded aboard the spacecraft for later playback to earth. All but one of the science instruments had been turned on and were functioning normally.

On 23 September 1977, Voyager 2 experienced a failure in the Flight Data Subsystem (FDS) circuitry which resulted in the loss of 15 engineering measurements. An effort to reset the FDS tree switch was performed on 10 October 1977 but was unsuccessful. The problem was now considered a permanent hardware failure and workaround alternatives were used. This failure affected 15 separate engineering measurements, an internal FDS measurement, and four redundant measurements.

The first Voyager 2 trajectory correction maneuver (TCM) was performed on 11 October 1977, achieving the desired correction to within one percent. In anticipation of experiencing a similar thruster plume impingement to that observed on Voyager 1 first TCM, an overburn and pitch turn adjustments were factored into the Voyager 2 sequence.

This TCM slightly adjusted the aiming point for the Jovian satellite Ganymede. The Voyager 2 closest approach to Ganymede was then planned for about 60,000 kilometers (37,000 miles) rather than 55,000 kilometers (37,000 miles) on 9 July 1979.

On 31 October 1977, Voyager 2 was commanded to acquire the star Deneb as a celestial reference point. Deneb lies on the opposite side of the spacecraft from Canopus (the normal celestial reference). Acquiring Deneb effectively required turning the spacecraft upside down. This was done to minimize the effects of the solar pressure, which were contributing to the frequent attitude control thruster firings to steady the spacecraft and also to allow an earlier pointing of the high-gain antenna to the earth. Voyager 2 stayed on Deneb until 29 November 1977, when Canopus was again acquired as the celestial reference.

Voyager 2 successfully performed sequence verification tests on 5, 7, and 8 December 1977. On 27 and 28 December 1977, the spacecraft performed a cruise science maneuver. This maneuver allowed calibration of several instruments by turning the spacecraft to look at the entire sky. The scan platform instruments were able to map the sky as the spacecraft rolled, and the ultraviolet spectrometer and photopolarimeter made their observations against the total sky background. The magnetometer and plasma instruments also obtained calibration data.

The cruise science maneuver consisted of rolling the spacecraft in one direction for about 5 hours (10 yaw turns) and rolling it about the roll axis for about 12 hours (26 roll turns). The last roll turn was finished 20 seconds earlier than the computer expected, activating a "safing sequence" aboard the spacecraft. The result of the anomaly included loss of approximately 4 out of 20 hours of the cruise science maneuver data and loss of a subsequent slew to observe Mars.

In February 1978, a degradation of the S-band radio solid-state amplifier in the high-power mode was noted. The amplifier was switched to the lower power mode and was monitored. Results of this monitoring indicated approximately 0.5 dB degradation in its output. The radio system has built-in redundancy, using both a solid-state amplifier and a traveling wave tube amplifier.

On 2 February 1978, at 11:04 GMT, while being tracked by DSS 44, the spacecraft downlink was lost. This was near the end of DSS 44's view period. When DSS 62 failed to acquire the downlink, a spacecraft emergency was declared at 14:07 GMT, and DSS 63 was released by the Viking project to support the Voyager emergency. Preliminary evaluation of the situation was that the spacecraft had lost Canopus lock. During the end of the DSS 44 view period, the station data were marginal due to the low elevation angle and high data rate. A Canopus sensor alarm occurred that was masked by the marginal data. (The alarm may have been caused by a dust particle passing through the Canopus sensor's view.) This set a flag in the spacecraft's computer, indicating that a timer had been set counting down six hours, by which time the flight team could determine if the sensor was still on Canopus. But the spacecraft flight team was called in and, after studying the problem, commanded the spacecraft back to HGA and acquired Canopus. After a computer readout was performed, confirming normal configuration, the spacecraft emergency was terminated at 21:25 GMT, 2 February 1978.

S-band link residuals through December 1977 showed that downlink AGC values for Voyager 2 were near nominal while symbol signal-to-noise ratios (SNRs) were about +2 dB. X-band performance for Voyager 2 was also within 0.5 dB of predicts.

Due to spacecraft anomalies and additional instrument calibration requirements, more spacecraft commands were sent to date than originally planned prior to launch. A total of 12,977 commands were transmitted to Voyager 2 by the end of December 1977. During the cruise mission phase, a command load was planned about once a month; however, actual activities have been close to weekly, plus real-time commanding to meet real-time situations.

Voyager 2 successfully passed through the asteroid belt which lies between the orbits of Mars and Jupiter. As of May 1978, Voyager 2 was more than 535 million kilometers (332 million miles) from earth, traveling at approximately 18.8 kilometers (11.7 miles) per second relative to the sun, with a one-way communication time of 29 minutes and 52 seconds.

On 25 February 1978, the photopolarimeter subsystem (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. Spacecraft telemetry data had previously indicated that the polarization analyzer wheel 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 the analyzer wheel seemed to have become unstuck and responded to the safing command. On 2 March 1978, a series of commands was sent to see if the erratic stepping continued, but during the testing, nominal stepping was observed.

On 5 April 1978, Voyager 2 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 seven 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 one. Receiver number one attained two-way lock and several commands were transmitted through the main receiver, thus causing a reset of the seven-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 seven-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 two (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-second intervals, the interval computed to give the highest probability of command reception. If these sweeps were unsuccessful, a larger sweep (XA ±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 11 April 1978.

On 13 April 1978, this Voyager 2 recovery sequence was initiated by DSS 63. Within 55 minutes, it was confirmed that commands had been received through receiver two. 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 minutes 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 four hours, proving that the receiver could be acquired and the spacecraft commanded.

Following the initial receiver two 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 synthesis frequency (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-controlled oscillator. At this time, the receiver was not in lock and the indicated spacecraft AGC was 20 dB below predicts. The downlink reference was now the free-running VCO. As a result, the doppler was meaningless, and the downlink signal was corrupted by VCO noise. Following the initial AGC acquisition, the indicated uplink AGC increases steadily for about 40 percent 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 was locked, the indicated spacecraft AGC followed a fairly smooth pattern for the remainder of the two-way period. The doppler prior to the first AGC was good one-way ultrastable oscillator (USO) doppler. The doppler between first AGC and loop lock was no good. The doppler from the loop lock to loss of AGC was good two-way doppler. The doppler following loss of AGC was good one-way doppler.

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

Voyager 2 was successfully commanded by a 26-meter station using this procedure on 18 April 1978. 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 25 April 1978, 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 3 May 1978. This was the first Voyager demonstration of a TCM minor adjust command 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.

A Voyager 2 command load was successfully uplinked to the spacecraft on 24 May 1978. The 33 minute load was sent twice, since only about 60 percent 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.

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. Procedural 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 continued, especially in the planning and analysis area, to insure that appropriate procedures were 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 were placed on the Deep Space Station operations, and in some cases the accomplishment was difficult because of manual intervention, the DSN met its commitment to successfully support the Voyager project during the encounter of Jupiter.

Superior conjunction occurred during July 1978. Voyager 2 entered a sun-earth-probe (SEP) angle of 5 degrees inbound on 9 July 1978 and an SEP angle of 5 degrees outbound on 23 July 1978. The minimum angle was 2 degrees. The S-band AGC and SNR degradations correlated with degradations recorded during the Voyager 1 superior conjunction.

F. CRUISE TESTING

Between Voyager 2 launch and Voyager 1 launch (5 September 1977), the recertification of DSS 14 was ensured by performing a Configuration Verification Test (CVT) on 4 September 1977. DSSs 12, 44, and 62 had been tracking the Voyager 2 spacecraft daily, so their configuration was still validated. The second CVT at DSS 14 was very successful and the station was placed under configuration control for the Voyager 1 launch.

The first conjoint deep space station (DSS 42/43) was taken down in July 1977 for the Mark III Data System conversion. The 42/43 combined System Performance Test (SPT) was conducted on 24 September 1977, signaling the end of System Performance Testing and the start of the two-month DSN testing phase.

Being a conjoint station, DSS 42/43 presented further problems in that one CMF was used to transmit data from both stations simultaneously. Although it was a minor change to the basic 64-m/26-m MDS configuration, the impact to operations or what to expect in the way of interaction was not fully understood.

At the request of DSS 42/43 management, a new testing technique was used. The first day was scheduled for onsite training, followed by Viking Operational Verification Testing (16 hours per day) completing the first week. Viking was selected because it was a project the operational personnel were familiar with rather than starting with a new project (like Voyager or Pioneer Venus).

The first Voyager OVT was conducted on 1 October 1977. This OVT was very successful and set the pattern for the rest of the DSN testing at DSS 42/43. Two OVTs per crew were conducted during the month of October 1977. All but one OVT was very successful. Station operations personnel were highly motivated and their performance for the most part was excellent. On 31 October 1977, the station was placed on operational status for Voyager support.

The Spanish Complex at DSS 61/63 was converted to the MDS System during the period of 15 October through December 1977. DSN operational testing started in early January 1978. Again, a minimum of two OVTs were conducted with each operational crew. Simulation Conversion Assembly (SCA) and communications equipment problems plagued the first half of testing. After these problems were cleared, the remaining tests were smooth. The station became operational on 31 January 1978.

DSS 11, the last of the Network to be converted, was taken down on schedule (mid-January 1978).

As the command and telemetry capabilities became available for testing in July 1978, a series of Operational Verification Tests (OVTs) were conducted during July and August 1978 to provide training for the stations and Operation Control Team personnel and to validate capabilities. DSS 12 was not tested at this time, but was tested in November 1978, at which time tests were conducted with all stations. Included in the GDS tests were updates of software that corrected anomalies or provided additional capabilities in the DSN, MCCC, or project software as well as the conversion of the MCCC to the Mark III Data System. The tests had varying degrees of success, mainly due to problems with the Simulation Conversion Assembly (SCA) in generating the higher data rates and the interfacing of new systems. However, the test sequence was successful overall, and the capabilities were verified for encounter support. In total, there were 26 Operational Verification Tests scheduled, each being approximately eight hours in duration and supported by a minimum of 13 DSN personnel. This effort required 208 station-hours and some 2700 man-hours to complete the task.

During November 1978, the DSN participated with the project in exercising the MCCC Operations Control Team (MOCT) anomaly detection and problem resolution capabilities. Anomalies, such as antenna offset, radio receiver anomalies, and weather anomalies, were induced into the system, and emergency or contingency plans were implemented.

The verification of the new support systems and the station updates required that GDS tests be conducted at various phases of system implementation. To validate the updates required 35 overall GDS tests and 53 individual station tests. Each test required approximately eight hours of station time and support by an average of 13 operations personnel. This resulted in expenditure of 424 station-hours and approximately 5500 DSN man-hours in addition to the man-hours of support provided by the MCCC and the project.

SECTION VII

VOYAGER 1 JUPITER ENCOUNTER

A. DSN SPECIAL IMPLEMENTATION

1. Introduction

The DSN updated the Network with many multimission type implementation tasks between the Voyager launch and the first Jupiter encounter. However, there were several DSN implementation tasks that were done in the year before the Jupiter encounter specifically for Voyager. These implementation tasks are summarized as follows:

(1) Goldstone (DSS 12) 34-meter S-band conversion.

(2) Expanded wideband communications circuits.

(3) X-band antenna feed modifications at DSS 14.

(4) 64-meter antenna second X-band masers.

(5) Prototype real-time array system.

(6) DSN Radio Science Subsystem.

DSS 12 34-meter S-X conversion was a mandatory task along with the expanded wideband data lines from 14 and 63. The rest of the implementation tasks were major enhancements to the Voyager 1 Jupiter encounter science, either in the form of capability or reliability.

2. Goldstone (DSS 12) 34-Meter S-Band Conversion

The DSS 12 S-X band conversion task was primarily to increase the 26-meter antenna size to 34 meters and provide a new X-band capability with this antenna. Other major improvements to this antenna which were part of the conversion task were the inclusion of a high-rate telemetry system and ranging system electronics. The 26-meter antenna was enlarged to 34 meters by adding two rows of additional panels to the outside of the dish. The enlargement of the antenna provided approximately 2.8 dB of additional S-band gain at Goldstone and an X-band antenna gain of about 66.9 dB. The Goldstone downtime was from June of 1978 through December of 1978.

3. Expanded Wideband Communications Circuits

The Voyager project requirement for 115.2 kb/s telemetry data in real-time required additional capability from Goldstone and Madrid, Spain, beyond that provided at 56 kb/s. Therefore, an expanded wideband 230 kb/s data circuit was requested and provided by NASCOM from Goldstone to the communications facilities at JPL for data routing to the project mission operations control center.

At the Madrid overseas station, a different approach was taken to allow the transmission in real-time of the entire project 115.2 kb/s real-time telemetry data stream. Here a system was engineered which would allow tying together three 56 kb/s wideband circuits. This system was called a trichanneler and turned out to be an engineering challenge because of the timing correlation that was needed between the three 56 kb/s modems.

4. X-Band Feed Modifications at DSS 14

Two new modifications were made to the DSS 14 radio frequency feed system. These two modifications were an X-band orthomode and a dual hybrid mode.

5. 64-Meter Antenna Second X-Band Masers

At all the 64-meter antennas, only one X-band maser was operational in 1978. The DSN had an undesirable 64-meter station reliability at X-band, because the failure of the X-band maser was a single point of failure in the X-band system. To correct this single point of failure, a second X-band maser was installed at each of the 64-meter antennas, which allowed backup and quick switching to the new maser in the event that the prime maser failed. These masers were costly and state-of-the-art. Difficulty was encountered in meeting the overall schedule.

6. Prototype Real-Time Array System

The prototype real-time array system was really driven by the need for an operational array capability at all complexes for the Voyager Saturn encounters. This prototype system was designed to allow the real-time combining of baseband signals from two different antennas. This combined signal was designed to provide an improvement at Jupiter data rates and signal margins. Because this was a prototype unit, only one was built. It was installed and tested at DSS 14 and was used in a DSS 14/DSS 12 array. The prototype unit was a state-of-the-art device which encountered many problems in its early development. The system became operational before the Voyager 1 Jupiter encounter and provided support for selected Voyager passes.

7. DSN Radio Science Subsystem

Prior to the Voyager mission, occultations were supported using an open-loop receiver with a fixed first local oscillator passing a bandwidth sufficient to encompass the event of interest, plus uncertainties, onto an analog recording. The analog recordings were shipped to JPL and digitized at CTA 21, and the resulting computer-compatible tapes (CCTs) were delivered to the experimenters. For Voyager, the total shift in frequency due to the Jupiter atmosphere was large, and the existing system could not be used.

A new subsystem was implemented; this new subsystem was called the DSS Radio Science Subsystem (DRS). This subsystem involved a computer-controlled programmable first local oscillator in the open-loop receiver that followed (using a series of linear ramps) the time-related frequency excursion of the expected signal of interest, thereby enabling the real-time bandwidth to be reduced to the point where real-time analog-to-digital conversion and production of a CCT recording were possible. This new system was implemented at DSS 63 for the first Jupiter encounter (see Figure 7-1).

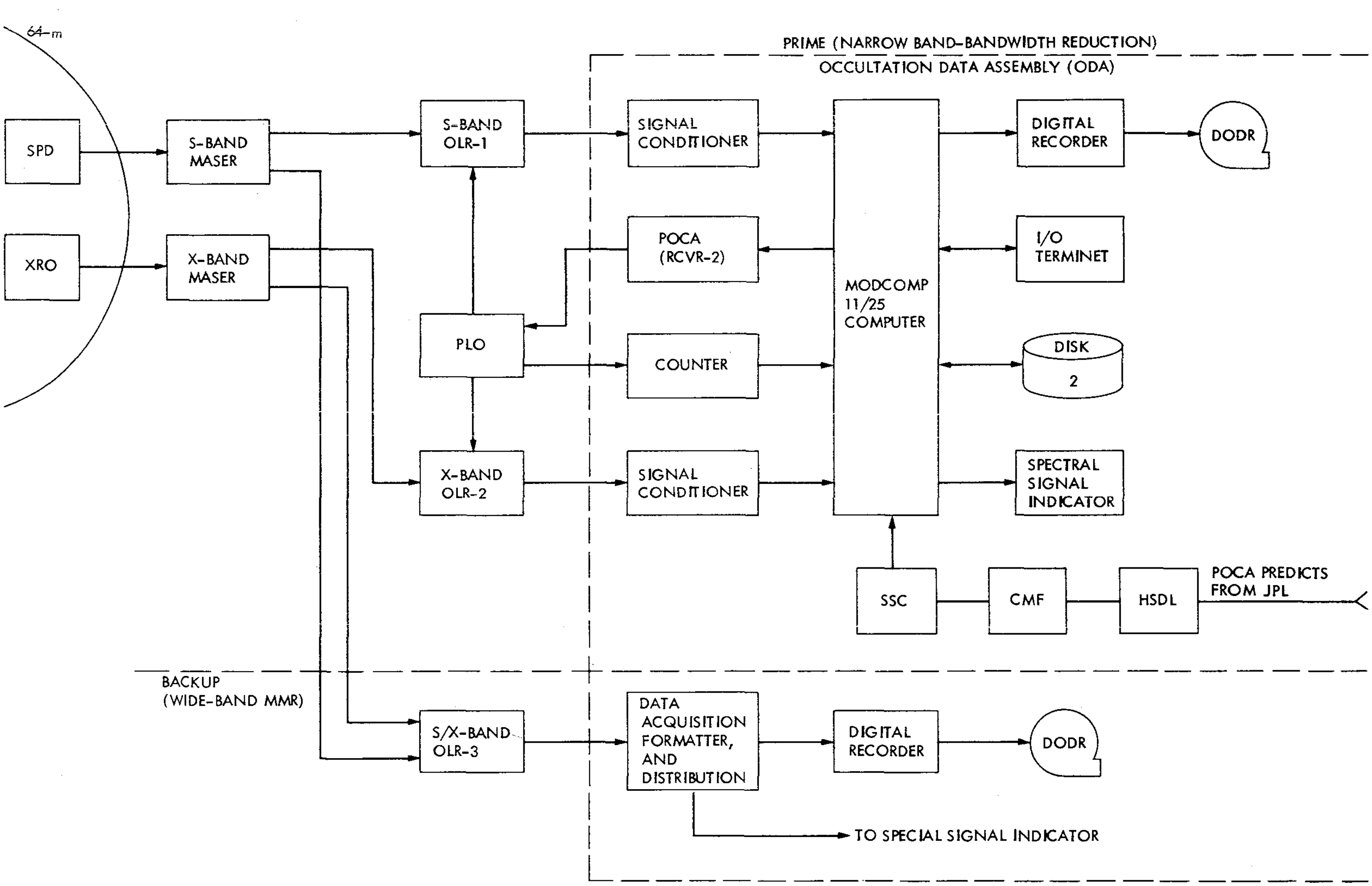

Figure 7-1. 64-Meter Open-Loop Recording Configuration

Preparations for support of the occultation experiment began approximately two months prior to the event. The project experimenters supplied the DSN with the information necessary for the configuration and setup of the Occultation Data Assembly (ODA). The DSN then produced ODA predicts for the station supporting the pass. The Network Analysis Team (NAT) transmitted the predict file to the DSS in advance of the pass to be supported. Other occultation data information was datafaxed to the DSS prior to the encounter pass. The station supported the experiment, supplied pertinent information to the Network controller, played back a portion of the recorded ODA CCT, duplicated the CCT, and then shipped the tape to JPL. In addition to taking data using the Multimission Receiver (MMR) ODA, the station used an Open-Loop Receiver (OLR) (300 kHz output) and the Digital Recording Assembly (DRA) to record wide bandwidth data for backup purpose only. Upon special request, these DRA recordings were shipped to CTA 21 where the bandwidth reduction equipment was used to produce a narrow bandwidth digital recording. The ODA CCTs shipped to JPL were delivered directly to the project. The high-speed portion of the recorded ODA data was processed by the Network Data Processing Terminal (NDPT), and an IDR was provided to the project, within 72 hours, for quick-look verification by spectrum analysis.

B. DSN PLANNED SUPPORT

1. Introduction

The Voyager 1 Jupiter encounter period duration was 96 days, extending from January 4, 1979 through April 9, 1979. The encounter period was broken into several phases: observatory, movie, far-encounter 1, far-encounter 2, near-encounter, and post-encounter. Table 7-1 summarizes the dates and events during each of these encounter phases.

This encounter was complicated by the fact that the Pioneer Venus probe entry had occurred in December 1978, and the Pioneer Venus orbiter was still in its prime mission, requiring sharing of the network tracking time, overall facilities, and capabilities. The Voyager requirements were many and varied. It required comprehensive support on an intermittent basis during the observatory phase and continuous 64-meter coverage starting with far-encounter 1 phase and continuing through the early portion of the post-encounter. The DSN station support periods planned for the Voyager 1 Jupiter encounter are summarized in Table 7-2.

There were significant challenges to the network besides scheduling and ensuring network capabilities. Special effort was required in the areas of telemetry, radio metric data, command, and radio science.

The network was configured to be able to upload large command sequences essentially error-free. Because of the Voyager spacecraft maneuvers planned during this period, the 64-meter 100-kW command capability was available as a contingency during the spacecraft maneuvers. The gyro calibration, which occurred just before Saturn encounter, was a critical maneuver which required different contingency commanding.

Table 7-1. Voyager 1 Jupiter Encounter Mission Phases

Phase	Dates	Events
Observatory	Jan. 4 through Jan. 30, 1979	Continuous general science and engineering Daily Jupiter imaging Trajectory correction maneuver A-3
Movie	Jan. 30 through Feb. 3, 1979	Continuous imaging of Jupiter atmospheric changes for 10 revolutions
Far-Encounter 1	Feb. 3 through Feb. 21, 1979	Trajectory correction maneuver A-4 Continuous general science and engineering Daily Jupiter and Galilean satellite imaging
Far-Encounter 2	Feb. 21 through March 4, 1979	Continuous general science and engineering Daily Jupiter and satellite imaging Bow shock and magnetosphere crossing Optical navigation
Near-Encounter	March 4 through March 6, 1979	High resolution imaging and closest approach to Jupiter, Io, and Ganymede Critical science and engineering events Jupiter radio science occultation
Post-Encounter	March 6 through April 9, 1979	Callisto closest approach Continuous general science and engineering Daily Jupiter and satellite imaging including dark side Jupiter viewing
Start Jupiter-Saturn cruise	April 9	Trajectory correction maneuver A-5

Table 7-2. DSN Support of Voyager 1 Jupiter Encounter, Planned Station Support

Phase	Dates, 1979	Station Coverage	Comments
Observatory	1/4 - 1/30	64-m from Madrid 26-m from Australia and Goldstone	Jupiter imaging at 67.2 kb/s from Madrid (DSS 63)
Movie	1/30 - 2/3	Continuous 64-m	Jupiter imaging at 67.2 kb/s
Far-encounter 1	2/3 - 2/21	Continuous 64-m	
Far-encounter 2	2/21 - 3/4		
Near-encounter	3/4 - 3/6		
Post encounter	3/6 - 4/9	Continuous 64-m	

Note: 26-m subnet to support Voyager 2 cruising spacecraft 16 hours per day.

The spacecraft telemetry requirements, which included general science and engineering and imaging, were such that a data rate of 115.2 kb/s was needed for a significant portion of the far-encounter 2, far-encounter 1, and near-encounter periods. Other imaging data rates that the DSN supported during this time period were 89.6 kb/s, 67.2 kb/s, and 44.8 kb/s, dependent on the link margin for that portion of the station pass.

During the observatory phase, the Madrid 64-meter antenna (DSS 63) obtained daily imaging of Jupiter and Galilean satellites at 67.2 kb/s. The Goldstone Complex was configured to allow baseband arraying at DSS 14 and DSS 12 on a demonstration basis during the Jupiter encounter period. The configuration was such that the loss of the DSS 12 baseband data would not degrade the overall telemetry from DSS 14. The first time this array system was used was during the far encounter 2 period on February 22, 1979.

The limitation of one 56 kb/s data link from Australia to JPL required playback of any data rate above 44.8 kb/s. For this reason, starting in March, 1979, DSS 43 was required to provide real-time imaging data rates no higher than 44.8 kb/s.

C. DSN OPERATIONS

The DSN operation support of the Voyager 1 Jupiter encounter period included the following activities:

(1) General science and engineering telemetry data collection and distribution.

(2) Radio metric data generation and distribution.

(3) Monitor data generation and distribution.

(4) Transmission of spacecraft command data.

(5) Navigation cycles.

(6) Trajectory correction maneuvers.

(7) Intermediate data record (IDR) generation.

(8) Jupiter and satellite imaging telemetry data collection and distribution.

(9) Radio science operations and data generation.

Although the encounter period was identified as separate time periods, the majority of the DSN operations activities spanned the entire mission phase. These activities started during the observatory phase and continued through the post-encounter phase. Some of these activities are discussed in the following paragraphs.

The period from January through August 1979 was the first time in the history of the DSN that it was required to support two projects, both in their prime mission phase, with the same priority on commitment of the tracking facilities. These two projects were Voyager and Pioneer Venus (PNV). The past philosophy of providing tracking coverage to an encountering spacecraft and exclude tracking of any other spacecraft for a period of time had to be abandoned, and a new philosophy adopted. This new philosophy included the tracking of at least two projects by a DSN station and providing maximum tracking time per spacecraft. To accomplish these objectives, the "quick turnaround" was devised for the 64-m network along with a new plan for station maintenance.

The basic premise of the new philosophy was that the involved Network Operations Project Engineers (NOPEs) establish guidelines pertaining to the configurations and levels of support to be used during the various phases of their mission. Each level of support corresponds to mission phase criticality and the extent to which a station must be calibrated and tested prior to tracking support. Four levels of support were defined:

(1) Critical redundant support.

(2) Critical nonredundant support.

(3) Normal support.

(4) Minimum (load and go) support.

The time required to perform the pretrack preparation (PTP) depends on the configurations and the level of support required. The time includes time for station reconfiguration but not time for normal housekeeping chores.

For the 64-m stations with S- and X-band downlinks, high-rate telemetry streams, and ranging for Voyager, the typical PTP time prior to quick turnaround averaged:

	Level 4	Level 3	Level 2	Level 1
VGR	1.5 h	3.5 h	6-8 h	8-10 h
PNV	1.0 h	3.0 h	6-8 h	8-10 h

NOTE: Radio Science Occultation Data Assembly (ODA) PTP time is not included in the Level 3 and 4 times.

Utilizing the normal PTP times as a starting point, the strategy utilized under the new philosophy essentially provides for: (1) performing the PTP at one time for both spacecraft, (2) reducing the time between tracks to a minimum, and (3) performing posttrack activities for both spacecraft at one time. (Approximately 30 minutes are added to period A when Radio Science equipment is required.)

The basic strategy under this new philosophy can then be broken down for the station considering two spacecraft support by specified time periods. (View periods for the 64-m network allow PNV tracking followed by Voyager tracking.)

A B C D E F
0 . . 3 . . 6 . . 9 . . 12 . . 15 . . 18 . . 21 . . 24

A = PTP (telemetry and command for both S/C) = 2 hours 20 minutes
B = Tracking PNV S/C ≅ 8 hours
C = Turnaround, Voyager (VGR) S/C = 30 minutes
D = Tracking VGR S/C ≅ 8 hours
E = Post-track activities for PNV and VGR ≅ 1 hour 30 minutes
F = Station maintenance ≅ 4 hours

Period A includes the following activities:

(1) RF calibration on S- and X-bands

(2) Ranging calibrations for Voyager (when required)

(3) Telemetry and command strings for Voyager

(4) Telemetry and command strings for PNV

(5) Command data transfer for PNV.

Period C (quick turnaround) includes:

(1) Loss of signal on PNV

(2) Reconfiguring the front end equipment for Voyager

(3) Mounting of new tapes

(4) Resetting command suppression

(5) Command data transfer on string number two while antenna moving in azimuth

(6) Continue antenna to point for acquisition of signal (AOS) of Voyager

(7) After AOS, reinitialization of telemetry and command string for Voyager

Period E (post track activities) requires:

(1) Ranging calibration for Voyager

(2) Recalls for PNV and Voyager

(3) Playback high-rate telemetry for Voyager

(4) Providing data package for both projects.

After some "implementation pains" at the stations, the concept was implemented and successfully used for support during this critical period. Maximum tracking time was provided for each project so that prime requirements were fully satisfied. Additionally, this new philosophy increased the station's overall utilization percentage for flight projects.

In order for the project to optimize the telemetry return and to ensure that each experiment objective was met, there were frequent bit rate changes during the encounter period. To support this operation, the DSN was required to be cognizant of the changes in terms of data requirements and the supporting equipment configuration. To obtain maximum data, it was necessary to determine whether the first bit of the new rate or the last bit of the old rate would result in maximum return. When a determination was made, the following procedure was used to support the decision.

Obtaining the First Bit of Data

(1) The station initialized for the new bit rate per the time in the SOE when the subcarrier frequency and modulation index remain the same as for the previous rate. The Subcarrier Demodulator Assembly (SDA) had to be in lock prior to stream initialization.

(2) When the SDA subcarrier or modulation index was changed simultaneously with the data rate, it was impossible to get the first bit of data since there was a delay in acquiring SDA lock.

Obtaining the Last Bit of Data

(1) The station did not initialize for the new bit rate until the telemetry stream dropped lock or was requested to acquire the new bit rate by Network Operations Control (NOC)

(2) Even though the telemetry stream was not initialized for the new telemetry rate, there was always the danger that the Symbol Synchronizer Assembly (SSA) and Maximum Likelihood Convolutional Decoder Assembly (MCD) would false lock to the new rate. Therefore, the station and the Network Operations Control Team (NOCT) guarded against false lock in this mode of operations, although neither the NOCT Real-Time Monitor (RTM) or Test and Telemetry System (TTS) were able to obtain synchronization on the data if the station was false locked. The best solution found was to initialize on the present bit rate within the guidelines of the SOE.

During the encounter phase, there were specific time periods when data collection was critical. These critical mission periods were defined. However, the project could and did declare as critical periods other than those previously identified.

Radio frequency interference (RFI) protection was considered applicable during the identified critical mission periods. Predictions were produced to cover known sources that could possibly cause problems, and the information was made available to the station. Procedures were also implemented by the stations to assist in quickly identifying and correcting internal interference sources. A procedure was also implemented for notification of observed interference to the JPL Operations Chief, the project, and other cognizant personnel for specific actions to insure maximum return of the mission data.

Analog recordings and redundant Telemetry Processor Assembly (TPA) DODRs were required during critical period support at the 64-m DSSs. The project accepted the additional risks when a 34-m DSS (DSS 12) was used to support critical mission periods. When telemetry data rates were above 44.8 kb/s, DSS 43 was not required to record redundant TPA DODRs, but analog recordings were required. During this time, DSS 43 utilized the backup TPA for data replay.

The primary concern during the encounter period was the timely receipt of the high-rate telemetry and imaging data at JPL. Wideband data lines were provided from all three of the 64-m stations. However, only the 230 kb/s capability from DSS 63 allowed transfer of the data rates above 44.8 kb/s in realtime. The 56 kb/s capability from DSS 43 required special consideration and strategy to provide the data in as close to real-time as possible. To accomplish this requirement, a special return procedure was instituted as follows.

Methods of data return from DSS 43. Two methods of telemetry return were employed: real-time and near-real-time.

DSS 43 processed and returned in real-time (on the 56 kb/s wideband data line, WBDL) all high-rate data with rates of 44.8 kb/s or lower.

For data rates above 44.8 kb/s, DSS 43 recorded real-time data on a DODR using one telemetry string and replayed the DODRs, using the second telemetry string, as soon as they were available. The data replays were done at the maximum line rate of the 56 kb/s wideband data circuit.

With the replays occurring at less than the real-time record rate, a telemetry return backlog existed until all DODRs had been replayed. Negotiations with other station users ensued to utilize their spacecraft track. All low-rate data, 40 b/s were returned via the HSDL in real-time.

For DSS 43 passes containing data rates above 44.8 kb/s, but with no optical navigation (OPNAV) data, the replay strategy was:

(1) DSS 43 logged all high-rate data on a DODR.

(2) As soon as the first DODR tape was completed, the station immediately started a replay of that tape over the 56 kb/s WBDL.

(3) When the first DODR tape replay was completed, the second tape was replayed and so forth until all data had been played in.

(4) DODR tapes were normally replayed in the same sequence as they were recorded.

(5) Some passes contained periods of high-rate data 44.8 kb/s less between periods of higher rate data. During these periods, the station suspended replay, returned the high-rate data in real-time, and resumed replays when the WBDL was again available.

During some of the DSS 43 passes, short periods of OPNAV data were contained in the high rate. It was a requirement of the Project Navigation Team that each period of this data be returned within a time not to exceed four hours after it was recorded on the spacecraft. To accommodate this requirement, the following replay strategy was used:

(1) Replay of the OPNAV data periods was specifically requested by the user. The requests were designated by data start and stop earth-received times.

(2) Due to the DODR replay backlog, the OPNAV replay requests, in some cases, required that DODRs be loaded for out-of-sequence replay. This was necessary to meet the OPNAV data-return time requirement.

(3) In such cases, the station completed the DODR tape replay already in process, mounted the tape containing the requested period, made the short replay, and then resumed the normal replay sequence where it left off.

During other specified periods, requirement for near-real-time DODR replay was for the latest data recorded. The station replayed the first completed DODR tape followed by the latest DODR tape to be completed, regardless of the order in which it was recorded. As each tape replay was finished, the next tape to be replayed was the most recent tape recorded. This out-of-order DODR replay continued until the end of the track, at which time the skipped-over tapes were replayed. The project exercised the option of requesting the replay of any completed DODR tape during these periods of "out-of-order" replay. Such requests were made by the user through the Voyager Mission Operations Controller (ACE) to the Operations Chief. The DSN honored these requests at the completion of the tape replay already in process and then resumed replay of the latest completed DODR.

1. DSS 43 Telemetry Backup

During certain real-time data periods determined by the Project to require a "hot backup" telemetry system with redundant DODR, DSS 43 configured both telemetry strings for real-time data and suspended data replays until the second telemetry string was again available.

For a data rate of 44.8 kb/s or less, the station was transmitting data from the prime telemetry string, while at the same time recording a DODR on the backup telemetry string. When the data rate was above 44.8 kb/s, the station recorded DODR on both telemetry strings for subsequent replay.

When high-rate data (real-time or replay) was not required from DSS 43 during the DSS 43/14 or DSS 43/63 overlaps, the station was requested to halt the wideband data output and record on DODR only.

The Intermediate Data Record (IDR) was the primary data product provided to the project by the DSN. Although telemetry data is provided in real-time or near-real-time to the Mission Control and Computing Center (MCCC) for the project's use, the IDR was still required to provide the permanent record and gap-filling of the data. In the case of radio metric data and tracking calibration data, the IDR is the only source of data to the project.

Monitor data is provided to the MCCC telemetry system (via the NOCC real-time monitor 5-8 data block) for inclusion with the telemetry data record. Command IDRs or fill tapes could be required by the project to complete their system data record as required.

Stringent requirements are placed on all IDRs provided by the DSN. In the case of telemetry during cruise, the requirement is for 97.5% of the inlock data blocks, and during critical periods, it is at least 99% of the in-lock data blocks. For radio metric data and tracking calibration data, the requirement is for the IDR to contain at least 95% of the data required to be transmitted in real-time by a DSS. As an indication of the impact of IDR production during this period, there were 367 telemetry IDRs (with an additional 74 supplementary IDRs) in February. Even this latter number increased in March during critical encounter activities. These IDRs were in addition to the optical navigation and radio metric data IDRs likewise produced.

2. Observatory Phase

The observatory phase included, as an early event, the sequential imaging of Jupiter in a series of narrow-angle photographs that were used to produce a motion picture sequence. A sufficient number of photographs was taken so that the rotation of Jupiter, the Red Spot, and other features were discernible. This phase was primarily supported by the Madrid 64-meter antenna.

3. Far-Encounter 1 Phase

Increased encounter support was provided with the spacecraft sequencing additional general science and engineering information. The period was identified by the high-density science data gathering and playback from the spacecraft recorder. The DSN procedures required close attention to the spacecraft activity to insure receipt of all data.

4. Far-Encounter 2 Phase

The phases started with a trajectory correction maneuver (TCM-4) to align the spacecraft. The TCM was executed successfully with full DSN support. The science density increased during the near-encounter preparation.

5. Near-Encounter Phase

One Jupiter-Earth occultation was observed during the DSS 63 pass on 5 March 1979. To record this event, both closed-loop and open-loop receiver data and radio metric data were provided as the complete radio science package. The new operational procedures developed for the open-loop receiver operation were used to provide the data.

For the open-loop recording, the digital original data record (DODR) recording began prior to the start of Jupiter occultation. It was necessary to collect baseline data prior to and after occultation. The project sequence of events was the controlling document for the ODA recording on and off times. Open-loop (S-band) backup recording was provided by the wideband (300 kHz) OLR and its DRA.

Voyager could not make use of the high-speed data line (HSDL) to get open-loop ODA data to JPL, except for preliminary quick-look data, because the number of station hours required to replay data via HSDL was prohibitive. The prime method of getting data to JPL was to ship the open-loop DODRs from the station.

DODR recording for Voyager used six DODR tapes per hour, five DODRs per hour for the narrow-band MMR ODA, and approximately one DODR per hour for the wideband OLR DRA. Technical assistance was sent from JPL to DSS 63 to support the occultation period.

New or once-used digital tape, at least 2300 feet in length for ODA and 12,500 feet in length for DRA, was required to be used for recording open-loop data, to ensure optimum data return. DSS 63 required about 30 good digital tapes (24 for narrow-band recording and 6 for wideband recording) to meet this requirement.

6. Post-Encounter Phase

The post-encounter phase consisted of obtaining additional science and engineering data while imaging Jupiter from a different aspect as the spacecraft departed from the planet.

D. RADIO SCIENCE

1. Introduction

Near-encounter radio science was obtained on the Voyager spacecraft on March 5, 1979, with the spacecraft providing a deep occultation of the planet Jupiter. This occultation lasted nearly two hours and provided a unique opportunity to obtain ionospheric and atmospheric measurements. During the period when the spacecraft was out of view from earth, a complex sequence was executed to allow the gathering of the spacial data required by the radio science experiment. The Voyager spacecraft performed a gyro drift maneuver simultaneously on 2 axes to track the virtual image of earth and the Jovian atmosphere with the boresight of the high-gain antenna.

The 64-meter antenna at DSS 63 was the prime station for the occultation data acquisition and was specifically configured to optimize the occultation data rate. The Australian 64-meter station (DSS 43) and the Madrid 26-meter station (DSS 62) were also used in providing supporting radio science information.

Real-time operation support for the occultation was provided by the Radio Science Data Team through the DSN Mission Control Team. Additionally, a Radio Science Advisor was sent to DSS 63 to provide onsite briefings and offer technical support for critical operations. A voice line from the Radio Science Team was provided to the DSS 63 Radio Science Advisor to allow close coordination of real-time operations. This voice circuit also provided for detailed technical support and performance assessment.

2. Radio Science Occultation

The radio science occultation primary support was provided entirely by the Madrid 64-meter station (DSS 63). The occultation occurred starting at about 20 degrees elevation, shortly after station rise. This allowed a good view of the entire occultation by DSS 63. The configuration of DSS 63 in support of the occultation is shown in the functional block diagram shown as Figure 7-1.

Both open-loop and closed-loop data were required from DSS 63. The open-loop data were provided in real-time to the Occultation Data Assembly, which provided selected bandwidth data recording using predicts generated by the Network Operations Control Center. This allowed detection bandwidths of 5 kHz at S-band and 15 kHz at X-band at a recording rate of 320 kb/s. Also, a redundant S-band receiver was used to make a backup recording at the DSS 63 Digital Recorder Assembly. The Digital Recorder Assembly recorded 300 kHz bandwidth directly from the backup receiver. No real-time bandwidth reduction was performed. The closed-loop data obtained at DSS 63 were at both S-band and X-band and used the block 4 Multimission Receivers with the maximum doppler sample rate at 10 samples per second.

DSS 62 also provided occultation coverage using closed-loop Block III receivers and provided high-rate S-band doppler data only. The role of the Australian 64-meter station was to perform the acquisition of final data to allow for a late radiation assessment of the ultrastable oscillator and to perform certain uplink events that were necessary to ensure Voyager spacecraft sequence execution.

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SECTION VIII

VOYAGER 2 JUPITER ENCOUNTER

A. DSN SPECIAL IMPLEMENTATION

1. Introduction

The period between mid-March and the latter part of June 1979 was authorized for implementation between the two Jupiter encounters. The DSN had several items of implementation that were either required as mandatory or as significant enhancements to the Jupiter encounter by Voyager 2. These selected new items were implemented between the two Jupiter encounters. The primary new implementation is summarized as follows:

(1) Real-time combiner

(2) NASCOM trichannel capability for Australia

(3) Goldstone multimission receiver

(4) Real-time SSI display, Goldstone to JPL

(5) Radio science predicts software change.

The implementation of items (3), (4), and (5) was needed to ensure a proper radio science configuration for the Jupiter Voyager 2 encounter.

2. Real-Time Combiner

The telemetry real-time combiner was a system conceived at a much earlier date and was being brought into the network between the Voyager 1 and 2 encounters on a demonstration basis. Specifically, for the Voyager Saturn encounters, the plan was to array a 64-meter and 34-meter site at each Complex to obtain approximately 0.8 dB additional signal-to-noise margin for the Voyager high-rate (44.8 kb/s) downlink telemetry. The prototype real-time combiner was tested at DSS 14, and there was a problem detected and corrected in the real-time combiner software. The Goldstone array capability became operational in July 1980, and the overseas Complexes had operations arraying systems in August 1980. The real-time combiner was designed to be inserted in the Telemetry System. It allowed baseband combining of the telemetry signals from two stations. For the Voyager 2 encounter of Jupiter, the prototype system developed at Goldstone was improved. This system baseband combined the DSS 12 and 14 signals with a goal of obtaining at least a 1 dB improvement in the overall telemetry signal as compared to the 64-meter received signal. Early in the development and testing phase, it was determined that the dual telemetry stream inputs improved the acquired composite signal by approximately 1 dB at Jupiter signal levels. This system was used to array both the 34- and 64-meter antennas at Goldstone during the week of near-encounter, and the system performed well.

3. Trichannel Wideband Data Line from Australia

During the Voyager 1 Jupiter encounter, real-time data from the Goldstone and Spain Complexes was available at 115.2 kb/s. The maximum available from Australia in real-time was 44.8 kb/s.

The way that 115 kb/s data was transmitted from Spain to JPL was to combine three 56 kb/s standard NASCOM circuits. This is described in Subsection VII-A-3. This same new implementation, requiring combining three 56 kb/s circuits, was implemented between Australia and JPL to support the Voyager 2 Jupiter encounters beginning on 27 May 1979. This multiple wideband capability was planned from Australia to Goldstone for Shuttle operation, and the implementation was advanced to cover Voyager 2 encounter support. A considerable number of problems was experienced during the testing phase, and a major effort was expended to resolve the problems. Problems continued through the early part of the observatory phase, but the near-encounter phase support was excellent.

4. Goldstone Multimission Receiver

DSN Engineering funded a new multifunction and multimission open-loop receiver to accept two channels of S-band data and two channels of X-band data. This receiver was specifically selected for use in gathering radio science information.

5. Real-Time SSI Display - Goldstone to JPL

The Radio Science Team requested an enhancement to the radio science configuration in the form of a video display provided in real-time from the Goldstone complex to the radio science operations area at JPL. The new implementation allowed the signal from the spectral signal indicator to be transmitted in real-time to JPL. This data was then processed by the Radio Science real-time monitor and fed to the Radio Science Team as a near-real-time spectral signal indicator display. Again, this system was an enhancement for the radio science effort and had some problems during the testing and early support periods. A major problem was unwanted noise through the SSI data.

B. DSN PLANNED SUPPORT

The Voyager 2 Jupiter encounter period duration was 127 days beginning on 24 April 1979 and ending on 28 August 1979. This encounter period was broken into several phases. The phases were the observatory, movie, far-encounter 1, far-encounter 2, near-encounter, and post-encounter. Table 8-1 summarizes the dates and events during each of these encounter phases.

Table 8-1. Voyager 2 Jupiter Encounter Mission Phases

Phase	Dates	Events
Observatory	Apr. 24 through May 25	Daily Jupiter and satellite imaging Continuous general science and engineering
Movie	May 25 through May 29	Continuous imaging of Jupiter atmospheric changes for 10 revolutions
Far-encounter 1	May 29 through June 27	Continuous general science and engineering Jupiter and Galilean satellite imaging Trajectory correction maneuvers B-3 and B-4
Far-encounter 2	June 27 through July 7	Jupiter bow shock crossing and magnetopause crossing Continuous general science and engineering Jupiter and satellite imaging including optical navigation imaging
Near-encounter	July 7 through July 10	Closest approach to Jupiter, its satellites Callisto, Ganymede, Europa, Amalthea, and Io Io torus observation Jupiter occultation.
Post-encounter	July 10 through August 28	Trajectory correction maneuver B-5 Earth and sun occultations

The DSN support of the Voyager 2 Jupiter encounter was complicated by the fact that another prime mission, Pioneer Venus, was requiring intensive support also during this time period. The intensive testing and operational support of both missions required maximum use to be made of all available DSN station time. This included a shortened time for station maintenance and effective testing plans.

The major challenges to the Voyager Jupiter 2 encounter were the same as for most encounters in the areas of command and radio metric data.

The spacecraft had several large command loads which required accurate DSN commanding to the spacecraft during the encounter period. Also, there were several maneuvers of the spacecraft during critical data gathering events that required the 64-m 100 kW transmitters to be checked out and available for contingency commanding on short notice in the event of a spacecraft anomaly.

During the early encounter phase, the basic project guideline was to provide continuous general science and engineering data at a data rate of 7.2 kb/s and periodic switching to the highest imaging mode possible. This imaging data rate would include the full 7.2 kb/s general science and engineering data. During the observatory phase, the Goldstone 64-m antenna (DSS 14) provided daily imaging of Jupiter and the Galilean satellites at 44.8 kb/s. The general science and engineering fields and particles experiment data were particularly important in the post encounter phases, because the spacecraft was in the Jupiter magnetotail and therefore required continuous 7.2 kb/s general science and engineering data.

The challenges to the DSN in the telemetry area were the obtaining of nearly 15,000 images of Jupiter and its satellites, a major portion of which were 115.2 kb/s. Trouble-free real-time arraying of the telemetry signal at the 34-meter and 64-meter antennas at Goldstone was the biggest challenge to the DSN for this encounter. This arraying technique enhanced the probability of obtaining 115.2 kb/s data during the critical days around near-encounter.

As on Voyager 1, several navigation cycles were required preceding the trajectory correction maneuvers B-3, B-4 and B-5, which occurred during the encounter period. Dual navigation cycles occurred before and after each of these trajectory correction maneuvers which required near simultaneous ranging, doppler, and planetary ranging measurements. Additional S- and X-band doppler measurements were requested between navigation cycles. This allowed additional measurements for assessment of the space plasma effect on short trajectory data arcs. The trajectory correction maneuvers B-3 and B-4 were supported by the Goldstone 64-meter antenna.

Part of the radio science data required during the encounter period was doppler and ranging to provide celestial mechanics measurements. This data was required during the entire encounter period and Jupiter near-encounter occultation measurements. The Goldstone 34-meter antenna tracked Voyager 1 for approximately four hours during the Voyager 2 occultation on July 10. This data was used as calibration information on the ray path.

The radio science detailed configuration and objectives are provided in more detail in part D of this section. The DSN planned station support for the various Voyager 2 Jupiter encounter phases is summarized in Table 8-2.

C. DSN OPERATIONS

1. Introduction

The DSN operations support of the Voyager 2 Jupiter encounter period included essentially the same activities as those included for the Voyager 1 encounter. The imaging sequences were changed to include further investigation of some of the Jupiter satellites to clarify information provided by Voyager 1.

Table 8-2. DSN Support of Voyager 2 Jupiter Encounter, Planned Station Support

Phase	Dates, 1979	Station coverage	Comments
Observatory	4/24 - 5/25	64-m from Goldstone 26-m from Australia and Madrid	Jupiter imaging at 44.8 kb/s from Goldstone (DSS 14) 26-m - DSSs 44 and 62
Movie	5/25 - 5/29	Continuous 64-m	Jupiter imaging at 67.2 kb/s
Far encounter 1	5/29 - 6/27	Continuous 64-m	Continuous 64-m coverage except days June 2 through June 8. During this period, Goldstone 64-m (DSS 14) and Australian and Madrid 26-m required
Far encounter 2	6/27 - 7/14	Continuous 64-m	
Near encounter	7/7 - 7/10		
Post encounter 1	7/10 - 7/14		
Post encounter 2	7/14 - 8/28	Australian and Madrid 64-m Goldstone 34-m (DSS 12)	Goldstone 64-m (DSS 14) supported special events. Only some conflicts with Pioneer Venus critical support

Note: The 26-M subnet was to support cruising spacecraft 16 hours per day.

Again the DSN operational support was structured to support the increased activity to insure receipt of all data. This effort continued throughout the encounter period.

During the Voyager 1 Jupiter encounter, a multiple wideband data line (MWBDL), capable of transmitting at data rates above 44.8 kb/s in real-time, was not available from DSS 43. The capability was available from DSS 14 and DSS 63. This configuration required that when DSS 43 was tracking, and therefore receiving, high-rate imaging data, the data be recorded on the station wideband tape recorder.

A MWBDL capability of 168 kb/s was planned from Australia to Goddard for shuttle operation, so it was proposed to advance the date of implementation to cover the Voyager 2 Jupiter encounter beginning with the movie phase on 27 May 1979. The implementation was pushed, and the capability was made available for operations, on a best-effort basis, on that date for the movie. A considerable number of problems were experienced during the testing phase, and a major effort was expended to solve the problems. The last real problems were experienced on 28 June. The period following through closest encounter was practically problem-free with very few error blocks being received.

A limitation of the system was the capability of Goddard and JPL to handle either, but not both, DSS 43 and DSS 63 data at the same time. Since the DSS 43 view period overlapped the DSS 63 view period, it became necessary to specify the time at which Goddard would switch beforehand; and, monitoring the switchover, the data interruption was only a matter of seconds.

This capability greatly reduced the data replay requirement for IDR production. Instead of having to recall all high-rate data (above 44.8 kb/s) from DSS 43, it was only necessary to recall the portion of data lost due to the switchover interruption, assuming no other problems occurred during a pass.

Approximately 851 IDRs were produced for the first 15 days of July, all being on time, with no backlog being experienced. For the entire encounter period, only 12 minutes of data were actually lost (nonrecoverable from the DODR) when the antenna at DSS 43 drove off point due to a hardware problem.

The arraying of DSS 12 and DSS 14 antennas provides the real-time combiner with the dual input of the telemetry stream, thus improving the acquired composite signal, which required special procedures as well as equipment.

It was determined during preliminary testing that the desired results could only be obtained from an effective basic telemetry string, operating at maximum efficiency. Therefore, it was determined that the stations should count down both telemetry strings and determine which had the better performance. The high performance string was then used for the data which was, in turn, used as the input to the real-time combiner.

Likewise, DSS 14 was required to count down the real-time combiner along with other station equipment. It was determined that nominal time for station PTP was two hours for DSS 12 and three hours for DSS 14. This type of schedule was maintained for pre-encounter day, with the pretrack preparation time being doubled on closest encounter.

2. Observatory Phase

The observatory phase start was identified by increased science and engineering observation recordings and playback of the data from the spacecraft recorder. The Goldstone 64-meter site (DSS 14) provided the primary imaging support during this period. The overall Goldstone imaging support was excellent.

3. Far-Encounter 1 Phase

The first activity during the far-encounter one phase was a trajectory correction maneuver (TCM-3) to refine the spacecraft arrival point. The maneuver was supported without incident. The next activity was the movie sequence. The movie was used to compare observations as received during the Voyager 1 movie.

An additional radio science experiment was confirmed in May 1979 for the Voyager 2 near encounter. The experiment was to evaluate plasma density during occultation by the Io torus.

This experiment represented an added requirement at DSSs 43 and 63, as DSS 14 already had occultation requirements that were not changed. To ensure this requirement could be satisfied, a series of tests was conducted during June 1979 to exercise the Radio Science Subsystem at DSS 43 and DSS 63. Testing at DSS 14 had already been scheduled as part of the radio science implementation sequence.

4. Far-Encounter 2 Phase

TCM-4 was accomplished to further refine the spacecraft arrival point. The period was identified as a high-activity period with high-density science return.

5. Near-Encounter Phase

DSSs 12 and 14 supported the encounter by arraying from 3 July through 9 July and again on 11 July. The average X-band telemetry signal gain from this operation for the period was 1.1 dB ± 0.2 dB (which was the anticipated signal gain).

The Io torus experiment required simultaneous tracking of both Voyager spacecraft from 9 July through 11 July. The basic requirement for the experiment was:

(1) Voyager 1: continuous track, acquire high-rate doppler (S- and X-band) and range data.

(2) Voyager 2: continuous track, acquire high-rate doppler (S- and X-band) and open-loop receiver recording.

Since the observations of the Io torus were characterized by narrow data spectra and small orbit uncertainties, it was advantageous to use very narrow open-loop filter bandwidths. The test plan utilized 1.0 kHz/3.0 kHz filter pairs for S- and X-band. Recording periods were scheduled when the spacecraft was two-way noncoherent. Special radio science predicts for Voyager 2 were provided to the 64-m stations. The doppler sample rate was set to one per second for the first 15 minutes of the recording period. The SSI was used to monitor and ensure that signals were within the open-loop receiver bandpass.

6. Post-Encounter Phase

The primary activity during this phase was TCM-5, which oriented the spacecraft for the Saturn cruise and the imaging sequence as the spacecraft withdrew from Jupiter on its course to Saturn.

D. RADIO SCIENCE

1. Introduction

The closest approach to the planet Jupiter occurred on July 9, 1979. On July 10, the Voyager 2 spacecraft was occulted by the planet Jupiter for 1.8 hours. In addition to the radio science occultation data on July 10, the DSN was required to provide support to the Io torus observation during the period from 9 July to 11 July. The primary objective of the Io torus observation was to measure the effects on dispersive doppler and range from Voyager 2 during the periods when the S-band and X-band signals intersect the region of the Io torus. The Voyager 2 earth occultation allowed studies of the Jovian ionosphere of the planet. Because this occultation was a grazing occultation, the ray-bending angle caused by atmospheric reflection never exceeded a few tenths of a degree. The atmospheric pressure required to cause bending to an earthward direction was only a few hundred millibars at the deepest point in the occultation. Therefore, the S-band and X-band signal received at earth was expected to be relatively strong. This signal was expected to be strong enough to provide a reasonable probability that the DSN closed-loop telemetry receivers would stay phase locked throughout the entire occultation. Because of the small bending angles, the frequency profile of the occultation was also expected to be well-behaved.

Calibration data were also collected for both the Jupiter occultation and the Io torus measurements. The occultation calibration measurements consisted of measurements on both the Voyager 1 and 2 RF signal paths, which allowed corrections for solar plasma and the earth's ionosphere. Calibration measurements for the Io torus again allowed solar plasma and earth ionosphere information in common regions of the ray paths of the Voyager spacecrafts to be defined. Real-time operational support for the occultation and Io torus data acquisition was provided by the Radio Science Data Team through the DSN Mission Control Team. Also, a Radio Science Advisor was sent to DSS 14 to provide onsite briefings and offer technical support for critical operations.

2. Jupiter Occultation

About 22 hours after the closest approach to Jupiter by Voyager 2, the spacecraft was occulted by the planet. This occultation lasted about 1.8 hours, and data acquisition during this period was a key objective of the radio science experiment. A special sequence and acquisition of special data types required by the experiment involved activities at the three DSN Goldstone stations as well as a special configuration of Voyager 2.

DSS 14 was the prime station for occultation data acquisition with DSS 11. Likewise, during Voyager 2 occultation tracking, DSS 12 tracked Voyager 1 to provide necessary calibrations of the Voyager 1 and 2 ray paths and to allow for solar plasma and the earth's ionosphere. The data from DSS 12 was applied to the Voyager 2 data to enhance the overall data quality.

Special configuration was required at DSS 14 to support this activity. Real-time bandwidth reduction for the prime open-loop data was performed by the Occultation Data Assembly (ODA) using predicts generated and transmitted from JPL. The detection bandwidths were 5.0 kHz at S-band and 15.0 kHz at X-band and resulted in a recording rate of 320 kb/s. Also, redundant S-band and X-band receivers were operated without bandwidth reduction in order to provide backup capability for the instrumentation supporting prime occultation data acquisition. The signal from the backup receiver was digitized in real-time and recorded on the Digital Recorder Assembly (DRA) with effective filter bandwidths of about 300 kHz at S-band and 1.7 MHz at X-band. Non-real-time processing of the DRA tapes was performed at CTA 21, as required.

Closed-loop data acquisition was performed using the Block IV multimission receivers at DSS 14 and Block III receivers were used at DSSs 11 and 12. High-rate doppler was required at all three stations with the highest rate being 10 samples per second.

The maximum refractive loss expected as the Voyager 2 signal passed through the Jovian atmosphere was to be about 24 dB. However, it was anticipated that the closed-loop receivers would remain in lock throughout the occultation period and that the SSI signal-to-noise ratio (SNR) would be adequate to provide good visibility of the open-loop received signal.

During the geometric earth occultation, it was found that the S/X-band signal profile dropped about 14 dB lower than anticipated and that the closed-loop receiver lock was lost during the occult period. The best estimate of the signal during this period is 170 dBm for X-band and 178 dBm for S-band. X-band was out of lock approximately 50 percent of the time due to signal fading, and S-band approximately 90 percent of the time due to threshold condition.

A Tracking System graphic display capability was provided for the monitoring of pseudo-residual and Tracking System noise during the occultation period. Terminal equipment was installed in the Network Analysis Team (NAT) tracking area and in the project Radio Science area. The primary display was a volatile digital TV, with a hard copy capability in NAT track. The system was controlled by NAT track in the fulfillment of their primary task; however, project display requests were accepted and honored whenever possible. Coordination was maintained between the project and NAT track over the normal voice circuit.

Likewise, remote Spectral Signal Indicator (SSI) displays were slaved to the DSS 14 open-loop receivers and installed in the NAT track area and in the project Radio Science area. Using this display, both project and NAT could monitor the station activity during occultation and correlate with other data available.

3. Io Torus Measurements

The Io torus measurements consisted of a selection of special doppler sample rates, range parameters, and Occultation Data Assembly data recordings at the Australian and Spanish 64-meter stations. Also, selected DSS 11 (26-meter) station support was required for ray path collaboration.

SECTION IX

JUPITER-SATURN CRUISE

A. INTRODUCTION

The Voyager 1 Jupiter-Saturn cruise began on 9 April 1979 with the completion of the Jupiter post-encounter phase and terminated on 22 August 1980 with the start of the Saturn observation phase. The Voyager 1 cruise period was 16 months and 13 days in duration.

The Voyager 2 Jupiter-Saturn cruise began on 28 August 1979 with the completion of the Jupiter post-encounter phase and terminated on 5 May 1981 with the start of the Saturn observation phase. The Voyager 2 cruise period was 20 months and 8 days in duration.

The cruise period activities included: (a) solar conjunction, (b) cruise science and trajectory correction maneuvers, (c) spacecraft calibrations, (d) navigation cycles (including delta-DOR), (e) relocation of Radio Science equipment, (f) development of new DSN capabilities, (g) upgrading of existing capabilities and procedures, and (h) both DSN testing and project operational testing.

B. DSN SPECIAL ACTIVITY

On 9 August 1979, the Madrid station was decommitted from project support operations and began an upgrade that would convert the station from a 26-meter to a 34-meter capability. This upgrade primarily increased the antenna size and included receivers for the reception of X-band signals. The station returned to an operational status on 9 March 1980.

The Programmed Oscillator Control Assembly (POCA) was moved from DSS 61 to DSS 62 for the period of upgrade activities so that the capability would be available to uplink Voyager 2. With the loss of the radio frequency tracking loop capacitor in Receiver 2 and complete loss of Receiver 1 it was necessary for the Voyager 2 uplink to be continually tuned to maintain the uplink. This equipment relocation allowed a combination of a 26- and 64-m station coverage for both Voyagers during the view period over the Spanish sector.

During the period 4 through 11 March 1980, Real-Time Telemetry Combiner (RTC) and arraying training operations indoctrination were conducted at Goldstone. Representatives from DSSs 43 and 63 attended and returned to their stations to prepare for the training and support at the conjoint facilities. The training period included classroom training, hands-on training, and actual support of three scheduled array passes. Applicable operations procedures were evaluated and updated as required.

The implementation of the S/X-band capability and upgrade of DSS 61 from a 26-meter-diameter antenna to a 34-meter-diameter antenna were completed on 1 March 1980. The subsystem testing was completed at the same time, and System Performance Tests (SPTs) started the following day. The SPTs were essentially completed on 12 March 1980. These tests were divided into two phases: one with antenna operation and one without antenna operation. This was necessary because previous inspection had determined that repair was required on the antenna gear boxes prior to returning the station to an operational status.

This gear box repair work was accomplished during the SPT time frame, restricting antenna operation during that repair function.

The implementation of the S/X-band capability and the upgrade of DSS 42 from a 26-meter-diameter antenna to a 34-meter-diameter antenna were completed on 28 March 1980. The subsystem testing was completed at the same time, and the SPTs started the following day. The SPTs progressed on schedule and were completed on 15 April 1980.

DSS 14 was removed from operational status on 14 March 1980 for an estimated 60-day period. During this time period, the antenna subreflector was to be replaced, the antenna panels realigned, and a subreflector controller installed. The time necessary for panel realignment was overestimated, and the station became operational on 9 May 1980. The work was completed on 30 April 1980. During the period 4 May through 8 May 1980, SPTs were conducted at the station and an OVT was performed on 8 May 1980. The first scheduled tracking passes after the OVT were considered demonstration tracks for final station validation.

DSS 62 was removed from operational status on 17 April 1980 for an estimated 25-day period. During this time period, the antenna gear boxes would be inspected and repaired as required. This work was the same as that accomplished at DSS 61 during the 34-meter upgrade activity. The station was returned to operational status on 12 May 1980.

During the time that DSS 61 was undergoing conversion, the Programmed Oscillator Control Assembly (POCA) was removed from DSS 61 and installed within DSS 62. This gave DSS 62 the capability of uplinking with Voyager 2. The POCA was removed from DSS 62 and reinstalled at DSS 61 on 21 March 1980 as part of the 34-meter capability.

During the DSS 42 conversion, the POCA was removed from the station and installed at DSS 44. This provided the 26-meter station uplink capability for Voyager 2 and, like the DSS 62 operation, relieved some of the load on the 64-meter subnet. The POCA was reinstalled at DSS 42 on 9 April 1980.

During this period, several new software packages providing the required capabilities for the Saturn encounter were tested and accepted for operation at the deep space stations. Companion packages for the Network Data Processing Terminals were also tested and accepted for operations at JPL in Pasadena.

(1) Antenna Pointing Subsystem (APS). New software was completed, tested, and debugged.

(2) Communications Monitor and Formatter Assembly(CMF). Major upgrade was completed and placed in operational use.

(3) Command System (CMD). Completed probationary and Ground Data System testing and placed in operational use.

(4) Metric Data Assembly (MDA). Major anomalies encountered. Software package returned for correction and incorporation with capabilities of the next version. New release data established.

(5) Meteorological Monitoring Assembly (MMA). Tested and inserted into operational use. Provides interface with MDA for Very Long Baseline Interferometry Subsystem (VLBI) support.

(6) Occultation Data Assembly (ODA). Tested and in operational use for VLBI and other baseline data recording.

(7) Planetary Ranging Assembly (PRA). Tested and in operational certification cycle.

DSS 12 was decommitted from support operations on 6 March 1981 and scheduled to become operational again on 24 April 1981. The purpose of the DSS 12 downtime was to improve the overall antenna efficiency.

The Block IV receiver telemetry detectors were modified to reduce degradation, thus providing four possible paths for the 64-m output to the RTC. A procedural means of measuring the RF path delay and time required for RTC pretrack preparation (PTP) was formulated.

The RTC installation was completed at the Goldstone DSCC in mid-May 1980. Antenna arraying, RTC training, and operational evaluation were started on 19 May 1980. This training evaluation consisted of a series of periods, during which both DSS 12 and 14 were scheduled simultaneously to track either Voyager 1 or 2.

The test activity allowed the station personnel to operate the RTC as they desired for the greater part of the scheduled period but required them to maintain a standard configuration for a specified period of time. Under this concept, the noncombined telemetry data were transmitted to the project to meet the DSN commitment. The combined telemetry string was displayed via the monitor stream so that the advisors at JPL could monitor the station activity. During the standard configuration period, the symbol SNR was recorded for both the 64-m telemetry string and the 34-m telemetry string and at both 29.8 and 44.8 kb/s. This recorded data was the basis for operational evaluation.

It was generally found that the RTC operated within the specifications. However, some problems were experienced with the new firmware boards since some components were prone to fail. Likewise, it was found that the condition of the entire telemetry string, including all components, greatly influences the combiner performance. In order to measure the combiner performance, it is necessary to know the performance of the telemetry string to ±0.1 dB. This required each component to be calibrated and within specifications to ±0.1 dB. The SNR spread between the 34-m and 64-m stations was found to be greater than anticipated, and part of the discrepancy was probably due to the telemetry string performance.

Eight array RTC periods were conducted with DSS 12/14 prior to completion of the RTC installation at the overseas Complexes. On 23 and 24 June 1980, the first arraying period was scheduled for both DSS 42/43 and DSS 61/63. The same training evaluation philosophy was observed during the subsequent tracking periods for these stations. The same findings and evaluation were made of the data from these DSCCs as were made of the Goldstone Complex. Variances were observed in the SNR spread between the stations, and in some cases, the spread was so great as to invalidate any combiner gain. Likewise, telemetry strings had problems in being locked up to the data, indicating marginal operation of some components.

The final conclusion from this testing was that a prerequisite to a successful encounter operation is a stable telemetry string and RTC, which have been carefully calibrated and tuned. Training passes were continued to be scheduled to allow the stations to be properly prepared for critical encounter operation with this configuration.

DSS 12 completed antenna upgrade work ahead of schedule and returned to operational status on 20 April 1980. A demonstration Voyager pass was conducted on that day to verify operational status. DSS 12 antenna gain improvements of about 0.7 dB were measured. The DSS 12/14 array system performance gain improved also as expected.

Much work was also done in providing additional Radio Science equipment and compatibility for the Voyager Saturn encounter. See Section X.

C. SOLAR CONJUNCTION

Voyager 1 continued in its Saturn cruise phase with solar conjunction activities during the period of August 8 through 20, 1979. Voyager 2 completed the post encounter activities on August 28, 1979 and entered the Saturn cruise phase. Solar conjunction activities were observed during the period August 8 through 29, 1979.

One of the primary activities supported by the DSN during July and August was the special radio science activity conducted during the solar conjunction of both Voyager spacecraft and the Pioneer spacecraft.

The solar conjunction provided the Voyager project with a unique opportunity to perform observations of the solar wind and solar corona as the ray paths from the Voyager spacecraft passed near the sun.

The observations enhanced the knowledge of variations of the solar wind and corona in the region of the sun. The listing below outlines representative dates and changes in the sun-earth-probe (SEP) angle during the solar conjunction.

Date, 1979	Voyager 1, degrees	Voyager 2, degrees
August 2	14	8
August 8	11	5
August 12	7	2
August 14	6	1
August 16	4	2
August 18	3	3
August 20	2	4
August 21	1	5
August 24	2	7
August 26	3	8
August 28	4	9
August 29	5	10
September 1	7	12

Forty-seven passes were scheduled for support of the solar conjunction activity; 24 passes were scheduled for Goldstone, 9 passes for Canberra, and 14 passes for Madrid. Each of the Voyager 2 passes required four hours of Occultation Data Assembly (ODA) recording, and Voyager 1 passes required three hours of ODA recording. Data collection began on July 24, 1979, from Madrid, on July 31 from Goldstone, and on August 8 from Canberra. Special configuration, and in some cases extra equipment, was required during the support period. The extra equipment was comprised of an Open-Loop Receiver Assembly (OLR) and a Multimission Open-Loop Receiver Assembly (MMR) used to provide data to the ODA recorder. The standard closed-loop receiver configuration for S-band and X-band radio metric data was used with selected doppler sample rates as specified for the particular pass.

The MMR and ODA equipment was used for the open-loop data at Goldstone and Madrid, and the OLR and ODA equipment was used at Canberra. Filters, sample rates, and record numbers were changed during the activity based on experience gained and modified requirements. Initially selected were 1 kHz S-band and 3 kHz X-band filters with 2000 sample/second and 8 bits quantization sample rate. Later, after special installation, 100 Hz filters were used with 200 sample/second and 8 bits quantization for S/X-band.

With the 1 and 3 kHz filters, Goldstone and Madrid calibrated the MMR output and/or ODA input power level for the S/X-band set at plus 12 dBm. With the 100 Hz filter used at all stations for S/X-band, the ODA input power level was set at plus 20 dBm.

Special ODA predicts were generated and made available from JPL for one- and two-way spacecraft modes. To minimize tape usage, the number of ODA records was initially set at 29,000 records, or a record time per tape of 4.1 hours, but later changed to 25,000 records, or 3.5 hours of data, to insure that all data were included on one tape.

As the SEP became smaller, it was found that the solar plasma exceeded prediction, and the 100 Hz bandwidth was exceeded. The stations were instructed to return to the 1 and 3 kHz filters and the 2000 sample/second and 8 bits quantization sample rate. The system noise temperature (SNT) also increased with the decrease in SEP, and it became necessary to reduce the MMR and/or OLR output power to the ODA to prevent saturation. Solar activity was more intense than expected; therefore, a table of SNT versus MMR and/or OLR output power reduction was required. The resultant values were:

SNT, K	Reduction in MMR and/or OLR output, dB
40	1
80	2
125	3
200	4
500	5
800	6
1260	7

However, in no case was the output power reduced to less than plus 13 dBm.

To compensate for this changing calibration requirement, the stations were required to obtain the S/X-band SNT from the strip chart recorders for each pass. The SNTs were recorded for future reference. When time permitted, the current SNT was used to update the MMR and/or OLR output power levels for the pass; if time did not permit, the data obtained from the previous pass were used. The station equipment and personnel responded effectively under these changing and varying conditions, and the total data requirement was met by the DSN.

Up to the time of the Voyager solar conjunction, there were no quantitative data on command link performance degradation at small SEP angles. As a result, each flight project was forced to adopt a conservative command policy as it approached a solar conjunction. The Voyager project used the opportunity during the solar conjunction period to collect such data. Command capability demonstration tests were conducted on selected Voyager 1 passes when the SEP angle was 5 degrees or less. The test consisted of four dummy commands transmitted to Voyager 1 four separate times during the test period. Each series of commands was transmitted at a different uplink power level. The four uplink power levels were obtained by using different levels of transmitter power and modulation suppression of the uplink.

To meet this requirement, the stations were required to perform special calibrations. Additional pretrack preparation time was included in the schedule to support this requirement. The 64-meter stations were required to calibrate their transmitters for 10 kW and 4 kW. The 26-meter stations calibrated their transmitters at 18 kW, 12 kW, and 8 kW. Ranging suppression was calibrated at the 64-meter stations for 3 dB, 4 dB, and 16 dB, while the calibration at the 26-meter stations was for 3 and 10 dB. All stations verified that command modulation suppression values were calibrated with 3 dB and 0.54 dB. The tests were successfully supported by the scheduled stations. The activity was highly successful in providing capability data and the results documented.

During the period, the stations routinely supported the various spacecraft activities and tests, such as radio frequency subsystem automatic gain control, command detector unit signal-to-noise ratio, antenna and sun sensor calibration, periodic engineering and science calibration, plasma calibration, magnetometer calibration, low-energy charged particles, tracking loop capacitor, etc. These efforts all required special preparation and tracking activities by the stations. The resulting support provided by the DSN was excellent.

D. VOYAGER 1

Voyager 1 continued on the Jupiter-Saturn cruise phase of the mission. In addition to the normal cruise activities, Voyager 1 performed some preliminary maneuvers and imaging activities in preparation for the Saturn encounter.

On 20 and 21 February 1980, a cruise science maneuver was performed by Voyager 1. The maneuver was conducted with no problems, and the spacecraft was reacquired when the antenna came back to earth point.

The scan platform was calibrated on 20 March 1980 and again 22 April 1980. Saturn exposures were taken and received during the calibration periods.

During the month of March 1980, the X-band drivers were turned off three different times for a total of 148 hours and 42 minutes. During these periods, only S-band telemetry data were received and processed by the stations.

During February through April 1980 a new research and development (R&D) type of data technique, delta differential one-way ranging, was used for the first time.

Several navigation cycles were completed with delta differential one-way ranging (delta DOR) activities occurring twice during each navigation cycle. The delta DOR activity was conducted by the 64-meter stations during mutual view periods. During the period that DSS 14 was down, DSS 13 provided the delta DOR support.

On 13 through 14 May 1980, a special cruise science maneuver was exercised by the spacecraft. The purpose of the maneuver was to allow a full-sky survey by the body-fixed instruments. The maneuver consisted of 10 complete yaw revolutions and 25 roll turns. During the maneuver, the spacecraft antenna was off earth-point for 18 hours and 47 minutes with no downlink for this period of time. DSS 63 (Madrid) successfully supported the activity at the start of the maneuver and the next day for the scheduled reestablishment of the downlink.

On 19 May 1980, the spacecraft was used for a dual uplink command test supported by DSS 12 (Goldstone) and DSS 63 (Madrid). The uplink command capability for Voyager 1, using a single 64-meter-diameter antenna station with an output power level of 80 kW into the spacecraft low-gain antenna, would be lost in mid-1982. A concept was developed to use dual uplink commanding via two 64-meter stations.

The concept consists of two 64-m simultaneous uplinks. The first part of the test had one 64-meter station uplink as a single-sideband sine wave subcarrier. This was accomplished by offsetting the carrier by 512 Hz at S-band. For test purposes, the uplink was modulated plus or minus 90 degrees with a 16 Hz square wave to simulate command bits. During the second part of the test, the uplink was set to the same frequency at both 64-meter stations.

The one uplink was modulated plus or minus 90 degrees with a 512 Hz square wave subcarrier to produce a double-sideband suppressed carrier command signal. High precision ramps were required by both stations, with a maximum allowable frequency error of 0.1 Hz at S-band to ensure acceptable operation. The test was not completely successful. However, the project assessment of the test was that uncorrected frequency variations between the two stations preclude the use of the noncoherent single-sideband sine wave subcarrier technique. The technique of combining two uplinks at the same frequency with one signal suppressed 20 dB with command modulation looked promising. Laboratory ground tests to determine the spacecraft threshold using this technique were proposed.

E. VOYAGER 2

Voyager 2 continued on the Jupiter-Saturn cruise phase of the mission. During the period of February through April 1980, several navigation cycles were completed with delta differential one-way ranging (delta DOR) activities occurring twice during each navigation cycle. The delta DOR activity was conducted by the 64-meter stations during mutual view periods. During the time DSS 14 was down, DSS 13 provided the delta DOR support.

The Voyager 2 operations during Voyager 1 Saturn encounter were relatively quiet, with the majority of the tracking support provided by the 26-meter network (DSSs 11, 44, and 62).

On 3 through 4 December 1980, a navigation cycle was conducted with Voyager 2. The navigation cycle was supported by DSSs 42, 63, and 12. Software problems with the interface between the Metric Data Assembly and the digitally controlled oscillator (MDA-DCO interface) required that the Voyager 2 navigation cycle support be conducted with a Programmed Oscillator Control Assembly (POCA) configuration. DSSs 42 and 12 were, therefore, required to reconfigure with POCA, instead of the DCO, before their supporting passes. DSS 63 was configured with the POCA and so was not required to reconfigure for support.

Near-simultaneous ranging was conducted during the DSS 63/12 and DSS 12/42 overlap periods, in addition to normal ranging. The navigation cycle was completed successfully, with required data being delivered to the project.

On 16 December 1980, a minicruise science maneuver was completed. The maneuver consisted of four yaw turns and four roll turns being accomplished. However, because the spacecraft antenna was off earth-point, no data were received. DSS 42 supported the activity that immediately preceded the maneuver, with DSS 63 supporting the reacquisition activity. Playback reception of the data recorded by the spacecraft during the maneuver was supported by DSS 43 on 17 December 1980.

On 26 February 1981, a trajectory correction maneuver (TCM-B7) was completed successfully. The objective of the maneuver was to place Voyager 2 on a more accurate trajectory to rendezvous with Saturn. The spacecraft was programmed to execute a negative roll turn followed by a negative yaw turn to align itself on the required burn vector. The TCM thrusters imparted a 0.574 meter/second delta velocity after a burn duration of 215 seconds. The spacecraft returned to earth-point by accomplishing complementary yaw and roll turns. The activity was supported by DSS 43 during the preparation phase and by DSS 63 during the actual maneuver. During the burn, the spacecraft was off earth-point. No telemetry data were being received in real-time, but they were being recorded aboard the spacecraft. The playback of the recorded data was accomplished during the DSS 43 view period on 27 February 1981.

The Saturn near-encounter radio science activities for Voyager 2 occurred during the view period of DSS 43. Since DSS 63 was the prime supporting station for the Voyager 1 Saturn Encounter Occultation Experiment, it was necessary to relocate the DSS 63 Radio Science equipment from DSS 63 to DSS 43. This equipment included the four-channel narrow and medium band multimission receiver plus the backup wideband four-channel multimission receiver and its associated digital recording assemblies.

DSS 43 sent its two-channel open-loop receiver to DSS 63. This equipment relocation was accomplished during the month of January 1981. DSS 14 has the narrow- and medium-band equipment comparable to DSS 43. Following successful installation of the equipment and subsequent System Performance Tests, a series of Operational Verification Tests was conducted with the new equipment and an updated version of the Occultation Data Assembly (ODA) software. The checkout of the new software (DMO-5123-OP-C) was started by DSS 14 on 4 February 1981, since their equipment was installed and operational at the time. Pioneer and Voyager X-band signals were used during this testing. The ODA OP-C testing started at DSS 43 on 19 February 1981 and at DSS 63 on 27 February 1981. Only minor problems were encountered. The operational procedures were refined and crew training accomplished during the testing. The software was transferred to operations on 16 March 1981, and tests continued to use live spacecraft data and accomplish the functions of recording open-loop data, playback of recorded data, and onsite validation of recording quality, as was required during the encounter.

In continuing effort to further refine tracking techniques to provide more precise spacecraft position information, the DSN was supporting doubly differenced range activity. The first activity supported occurred on 21 December 1980. This technique required that both DSS 61 and DSS 12 track and range on Voyager 2; then, after a quick turnaround, track and range on Voyager 1. The turnaround from Voyager 2 to Voyager 1 was accomplished in 20 minutes. The stations were required to perform pre- and post-track calibrations on the ranging equipment for both spacecraft. This was a new requirement, as a station normally tracks only one spacecraft and performs the necessary pre- and post-track calibrations to support that one spacecraft. Although there were some problems in preparing for and executing the activity, the results looked promising. Another test was supported on 31 January 1981 by DSS 61 and DSS 12. Fewer problems were experienced during this test, and the results indicated further testing was needed to provide more data for evaluation.

Metric Data Assembly software, DMK-5106-OP-F, which provides the capability to automatically control the digitally controlled oscillator (DCO) and the uplink frequency required for tracking Voyager 2, started engineering testing at Goldstone on 6 January 1981. DCO implementation at the 34- and 64-meter stations was completed on 26 February 1981. After a series of Voyager demonstration tracks, during which problems were identified and corrected, a preliminary operational disk was provided. The Goldstone stations began Probationary Testing on 5 February 1981, with this disk supporting all projects. The software was also sent to the overseas stations where they began Probationary Testing on 16 February 1981. The software was transferred to operations on 2 March 1981 for an operational certification period by the stations prior to the official replacement of the previous operational support software. The software became the prime support software on 28 March 1981.

The problems caused by the failure of the receivers on Voyager 2, with the resultant 200 Hz bandpass in the operation receiver, are complicated by spacecraft internal temperature changes. It was determined that, after various spacecraft activities, compartment temperatures increased and changed the center frequency of the receiver bandpass and the rate of drift as the temperatures returned to normal. Therefore, after these spacecraft activities, the best-lock frequency (BLF) is unknown, and normally a command moratorium is declared due to the uncertainty of establishing a proper uplink. During the Saturn near-encounter, after the spacecraft came out of occultation, this condition would exist, but it was necessary to command the spacecraft sooner than a moratorium would allow. To provide background data on the frequency offset and to allow better estimates of the BLF after these activities, the DSN supported special tracking procedures called "adaptive tracking and BLF determination." Essentially, after a spacecraft temperature change, the 34/64-meter station accomplished the BLF determination sequence.

This is a sequence of five predetermined ramps by the DCO through the estimated BLF. The data are analyzed in near-real-time to refine the BLF. The adaptive tracking sequence was exercised, during which time the DSN was provided a frequency offset to "snap to" then to automatically ramp with the appropriate predicts. The frequency drift from the predicted was used to keep the uplink centered in the receiver bandpass. This procedure was continued as long as necessary to ensure a proper uplink for commanding activities. This procedure relied on the DCO and the capabilities of the MDA software DMK-5106-OP-F auto-matic uplink feature.

The adaptive tracking procedure (whereby the uplink frequency is changed in real-time, based on current estimates of the receive frequency) was exercised three times during the reporting period. The first time was on 13 April 1981 and was supported by DSSs 14 (Goldstone) and 63 (Madrid). The activity occurred after a spacecraft activity that had caused a temperature change and corresponding receiver VCO frequency changes. DSS 63 (Madrid) performed the best-lock frequency (BLF) determination ramping and the initial adaptive tracking frequency offsets, with DSS 14 (Goldstone) continuing the offsets. The second period occurred during a target maneuver with the BLF determination ramping results shortly after the reacquisition of the spacecraft. Adaptive tracking offsets were performed by DSS 63 and DSS 11 (Goldstone). The last period occurred on 17 April 1981 with the BLF determination ramping again being performed by DSSs 63 and 14. The tests were successfully completed, and valuable training accomplished by station personnel.

The target maneuver mentioned above was performed by Voyager 2 on 15 April. The spacecraft performed a negative yaw turn followed by a positive roll turn in order to position the photometric calibration plate to be illuminated by the sun with a 30 degree angle of incidence. The return to earth-point was accomplished by a negative roll unwind followed by a negative yaw turn. The spacecraft was off earth-point with no downlink for 3 hours and 31 minutes.

DSS 63 supported the entire manueuver during a tracking pass, including the adaptive tracking activity. DSS 63 used the Spectral Signal Indicator (SSI) capability to assist in the search for the return to earth-point and reacquired the spacecraft downlink signal on time.

On 21 through 22 April 1981, DSS 61 (Madrid) and DSS 12 (Goldstone) supported another dual-spacecraft, dual-station differenced range exercise with the Voyager 1 and 2 spacecraft to provide additional data on the technique. Again both stations tracked both spacecraft during their view period. DSS 61 started the procedure by tracking Voyager 2. After DSS 12 rise, a transfer was performed from DSS 61. DSS 61 then made a turnaround to Voyager 1. DSS 62 was tracking at the time and made a transfer to DSS 61. DSS 12, after tracking Voyager 2 for the specified period of time, turned around Voyager 1 and received the spacecraft from DSS 61. The passes went smoothly, and the data was evaluated along with the data provided by previous tests. The results indicated that all four legs from one of the differenced ranging passes to date appeared acceptable. However, the long RTLT, of both Voyager spacecraft and the need of four good legs left areas of ambiguity;

therefore, the results for Voyager were inconclusive, although, for shorter RTLT, the method is very feasible, as was demonstrated with the Viking Orbiter/Lander.

On 28 through 29 May 1981, a cruise science maneuver was performed by Voyager 2. The maneuver consisted of 10 negative yaw rotations followed by 25 negative roll rotations, which allowed a full-sky survey by the spacecraft body-fixed instruments. During the maneuver, the spacecraft was off earthpoint for 18 hours and 53 minutes, during which time there was no downlink from the spacecraft. DSS 63 supported the start of the maneuver, which included the real-time command to enable the maneuver and the loss of the downlink at the start of the yaw turns. The next day, during the DSS 63 tracking pass, the spacecraft completed its roll sequence and returned to earth-point. DSS 63 reacquired the downlink at the predicted time. The playback of the recorded maneuver data started about two hours later. The playback was received by DSS 63 at the start of, and completed during, the subsequent DSS 14 pass.

F. CRUISE TESTING

The Network Operations Project Engineer (NOPE) for Voyager conducted Operational Verification Tests (OVTs), following the completion of the SPTs, as the final testing step in returning the station to an operational status. The OVTs were structured so as to meet the verification requirements for all projects. These tests were conducted long-loop with telemetry data being generated by the Network Operations Control Area (NOCA) simulation and/or MCCC simulation and transmitted to the station for standard processing. This mode of testing not only verified the normal station processing equipment, but the Simulation Conversion Assembly (SCA) in preparation for future encounter Ground Data System (GDS) testing. Each station operational crew supported two OVTs so that a training requirement was likewise completed.

The same philosophy was followed at DSS 42 for verification of operations as was followed for DSS 61. Under this testing and training philosophy, the maximum return was realized from the utilization of the station resources. This resulted in the highest degree of confidence as to the station's operational capability.

Testing of the Radio Science System, particularly the recording of open-loop receiver data, is relatively easily scheduled as compared to real-time combining, because any spacecraft X-band data can be used. The station had been making such recordings for training and testing purposes. In addition, two ORTs had been conducted. The first ORT was a preliminary training exercise since much of the equipment had not been installed at the stations. ORT-2 was likewise considered incomplete, because the SSI, PPM, backup Multimission Receiver (MMR) at DSS 63, and MDA OP-E software were not available (not installed or not functioning) for test support.

Mission Configuration Tests (MCTs) were conducted by the DSN as the new equipment was installed. A successful ORT was conducted with DSS 43 on 24 July 1980; however, the DSS 63 portion was cancelled due to X-band maser problems at the station. ORT-3 was scheduled to be conducted concurrently with the Near-Encounter Test in August 1980.

A Near-Encounter Test was conducted on 19 through 20 August 1980. The test simulated the 18-hour period around Voyager 1 closest approach to Saturn. During the test, both the 34-meter and 64-meter deep space stations were configured and supported the project in the same manner as was required during the actual closest approach. During the Near-Encounter Test, a Radio Science Operational Readiness Test (ORT-3) was conducted with DSS 43 and DSS 63. The test period corresponded to the one required to support the actual closest approach and occultation periods.

Although the overall support provided by the DSN was considered satisfactory, several areas were identified for which additional attention was required. It was found that the arrayed antenna performance was lower than expected. Problems causing this were suspected to be telemetry string degradation due to improper calibration, adverse weather conditions affecting the X-band data, and variations between the 34-meter and 64-meter stations. Emphasis was given to improving the array performance for the movie sequence that was included in the observation phase for Voyager 1.

Problems were also encountered during the Radio Science ORT-3. Occultation Data Assembly halts were experienced, which caused some data loss. Appropriate calibration on the antenna at DSS 63 could not be performed due to a heavy rain storm which took place during the pretrack preparation period. Although the Spectral Signal Indicator (SSI) and the Precision Power Monitor (PPM) were generally good, problems were experienced in displaying the data at JPL. These were determined to be procedural problems that had not been fully resolved prior to the test, due to the newness of the capabilities. Additional voice communications had been provided for the radio science support, which was improperly configured and caused operational confusion.

Other minor operational problems and procedural and equipment failures were experienced that provided insight into the events that could occur during the actual approach. The test results provided valuable information regarding the areas for improvement and problem resolutions. Internal testing validated that the proper corrective action was taken. Preparations for the Voyager 2 Saturn encounter became the primary DSN support activity. The first general activity was to revalidate the array configuration of the 34/64-meter stations and to provide training for the station personnel. A series of array tests began on 1 April 1981 for DSS 42/43 (Australia) and DSS 61/63 (Madrid) and continued periodically throughout the period.

The DSS 12/14 (Goldstone) tests were scheduled to begin on 20 April. The tests went comparatively smoothly, with equipment operation well within the desired performance range and personnel displaying operational proficiency.

The Radio Science Operational Verification Tests (OVTs) at DSS 43 (Australia), started in March, continued periodically throughout the period. Several equipment and procedural problems were identified during the tests. The precalibration and configuration requirements were a matter of concern and took close coordination to ensure understanding by both the station and the Radio Science personnel. The main equipment problem appears to have been in the recorders and the malfunction of the recorder bypass switch; the reproduce selection switch caused early concern until the problem was resolved. The recordings continued to be evaluated to ensure that the Intermediate Data

Records (IDRs) reproduced from the recorded data were complete and processible by the user. This process continued throughout the period. The activity reached a milestone on 1 July with the system being exercised during the Radio Science Operational Readiness Test (ORT) number two by the Voyager Project Radio Science Team.

Voyager Ground Data System (GDS) Tests were required to validate telemetry, monitor, and command data end-to-end system operations with the updated software prior to encounter operation. The facilities of CTA 21 Compatibility Test Area, JPL) were used on 1 and 6 April to perform the initial validation. The tests were successfully completed. A long-loop GDS test was scheduled with DSS 43 (Australia) on 13 April 1981. Although DSS 43 had a problem with the interface between the Coded Multiplexer-Demultiplexer and the Simulation Conversion Assembly (the CMD-SCA interface) that made it necessary to loop back the simulated high-rate data at the CMD input jack panel, the test conductor concluded that the test was successful and that further testing was not required.

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SECTION X

VOYAGER 1 SATURN ENCOUNTER

A. DSN SPECIAL IMPLEMENTATION

1. Introduction

The DSN needed to do a considerable amount of new implementation for the Voyager 1 Saturn encounter. This was required because of the need for high-rate imaging at Saturn, more accurate radio metric data, uplink tuning and command improvements, and a new radio science configuration.

The primary new DSN implementation is summarized as follows:

(1) DSS 61 and DSS 42 S-X band conversion.

(2) 64-meter antenna improvements.

(3) 64-meter X-band low-noise masers.

(4) Telemetry system Real-Time Combiner.

(5) Radio Science System improvements.

(6) Command System software improvements.

(7) Metric Data Assembly software update for automatic uplink tuning.

(8) Planetary ranging assembly software improvements.

(9) VLBI System implementation.

The implementation described in items (1) through (7) above was needed to ensure the success of the Saturn encounter. Items (8) and (9) were implemented to provide considerable enhancement to the Voyager science.

2. 34-Meter S-X Band Conversion

The purpose of the 34-meter S-X band conversion was primarily to increase the 26-meter antenna to 34 meters and provide X-band and S-band capacity from these antennas. Two other major improvements to these antennas were the inclusion of a Planetary Ranging Assembly and a high-rate telemetry data system. Three sites were scheduled for the 26-to-34-meter upgrade. The Goldstone site (DSS 12) was completed in 1979 and used for the Voyager Jupiter encounters. The Madrid site (DSS 61) and the Canberra site (DSS 42) were upgraded between the Jupiter and Saturn encounters, with Madrid implementation occurring first and Canberra modified after Madrid was completed. The downtime for DSS 61 was 9 Aug 1979 through 1 March 1980. The Canberra downtime was from March 1980 through 15 May 1980.

3. 64-Meter Antenna System Improvements

There were several implementation efforts for the 64-meter antennas aimed at improving their effective aperture. DSS 14 had a subreflector replaced and the outer panels of the antenna reset. This allowed DSS 14 to improve the antenna gain by approximately 0.5 dB. All three 64-meter antennas had subreflector autofocus control capability installed, which improved the overall gain of the antenna at various elevation angles. In addition, DSSs 63 and 43 had dual hybrid mode feeds installed which allowed two S-band signals and two X-band signals to be obtained at the same time. This capability was needed at both sites for upcoming Saturn encounter radio science support where both right-hand circular and left-hand circular polarized signals were needed at S- and X-band. Also, at all the 64- and 34-meter sites, a rain blower was installed which blew air over the dichroic plate on the feed horn and helped to decrease the degradation caused by water. These were successfully installed at all sites and appeared to work quite well during light rains.

4. 64-Meter X-Band Low-Noise Masers

A state-of-the-art X-band maser was built for each of the 64-meter sites plus one spare. These state-of-the-art masers decreased the system noise temperature from approximately 27 K to 20 K. These masers provided an additional equivalent aperture gain of approximtely 1 dB. Being state-of-the-art masers, there was considerable difficulty in the system development, and none of the masers arrived per the original schedule. There were also some difficulties in maintaining the bandwidth goal of 100 MHz, but all the masers had sufficient bandwidth at time of delivery to meet all Voyager requirements. The masers were delivered first to DSS 14, then DSS 63, and finally DSS 43.

5. Telemetry System Real-Time Combiner

Real-Time Telemetry Combiners were developed and provided to all of the 64-meter sites. The purpose of these real-time combiners was to allow the merging of telemetry baseband signals from two antennas simultaneously. This purpose was accomplished, and the expected additional 0.8 dB signal-to-noise margin was obtained.

6. Radio Science System

The Radio Science System requirements for the Saturn encounters called for considerable new radio science equipment. This new equipment was needed to support the Saturn near-encounter radio science, which included occultation of Saturn and its rings and a ring scattering experiment. The Saturn occultation was planned to be observed by both Australia and Madrid, and therefore, equipment was needed at both sites. DSS 63 was the primary site for Voyager 1 Saturn radio science; therefore, equipment to be installed at that site was considerably more extensive than at Australia. DSS 63 new equipment improvements included a new 4-channel multimission receiver, increased Occultation Data Assembly bandwidth software and hardware, Precision Power Monitor, and Spectral Signal Indicator remote display capability. Also a backup Digital Recorder Assembly was installed at DSS 63 to record wideband radio science.

Radio Science updates at DSS 43 included a Precision Power Monitor and Spectral Signal Indicator remote display capability.

7. Command System Software Improvements

The DSN Command System Software was changed to improve the Command System operability with the Voyager Project Command System. This software change eliminated five Voyager Ground Data System lines on the DSN Command System. The DSN software development stayed pretty much on schedule and was operational in May 1980.

8. Metric Data Assembly Automatic Uplink Tuning

A new Metric Data Assembly software package was prepared to allow better support of the Voyager Saturn encounters. This software upgrade included automatic uplink tuning and Digitally Controlled Oscillator controller interface capability as two of its major capabilities. A planned automatic best-lock frequency sequence was deleted from this software package because of the difficulty of providing this software on a schedule acceptable for the Voyager Saturn 1 encounter.

Considerable problems were encountered with testing both the Metric Data Assembly software package and the Digitally Controlled Oscillator and its interface with the MDA software.

9. Planetary Ranging Assembly (PRA) Software Improvements

A Planetary Ranging Assembly hardware modification and associated software were implemented to increase the PRA bandwidth by 500,000 hertz. This software improvement was primarily to allow increased accuracy. A sun-earth-probe angle modification was also planned for the original delivery but was dropped out of the original software because of difficulties of meeting the planned delivery dates. The sun-earth-probe angle modification was delivered at a later date and provided increased data accuracy for solar conjunction measurements made by the Voyager project.

10. VLBI System Implementation

There were several Very Long Baseline Interferometry System implementation efforts associated with Voyager. The first and most important of these was developing the Block I VLBI to gather a new radio metric data deliverable, differential time delay measurements, to the Voyager project for use in calculating delta differential one-way ranging. The differential time-delay measurements delivered to the project were provided on an engineering best-effort basis for the Voyager 1 Saturn encounter. The testing of the Block I VLBI was to develop a reliable configuration to provide the differential time delay measurements that were obtained from each of the 64-meter Complexes. This Block I VLBI was delivered in an operable configuration for the Voyager project use in June 1980. Another VLBI implementation task which was accomplished to provide the necessary information to allow delta DOR was the development of a radio source catalog. This catalog allows measurements between accurately known radio sources and the Voyager spacecraft.

B. DSN PLANNED SUPPORT

The Voyager 1 Saturn encounter period extended for a period of 117 days from 23 August 1980, to 15 December 1980. The encounter period was broken into several phases: an observatory, far-encounter one, far-encounter two, near-encounter, and post encounter. The following table summaries the dates and events during each of these encounter phases:

Table 10-1. Voyager 1 Saturn Encounter Mission Phases

Phase	Dates	Events
Observatory	Aug. 23 - Oct. 24	Solar conjunction (9/6 - 9/28) Daily Saturn imaging and general science and engineering Saturn movie (9/12 - 9/14)
Far-encounter 1	Oct. 24 - Nov. 2	Daily Saturn imaging and general science and engineering Trajectory correction maneuver A-8
Far-encounter 2	Nov. 2 - Nov. 12	Trajectory correction maneuver A-9 (Nov. 7) Daily Saturn and satellite imaging and continuous general science and engineering data Saturn bow shock crossing and Saturn magnetopause crossing
Near-encounter	Nov. 12 - Nov. 13	Closest approach to Saturn and satellites and rings. Saturn and ring occultation and ring scattering experiment
Post-encounter	Nov. 13 - Dec. 15	Daily Saturn, satellite, and/or ring imaging and continuous general science and engineering Spacecraft health evaluation

To support the many Voyager requirements during the observatory phase, the DSN provided intensive and comprehensive support using the entire DSN. There were several challenges to the Network which required special effort in the areas of command, telemetry, radio metric, and radio science data.

Several large command loads were sent during the near-encounter period which required timely uplink. The Voyager spacecraft performed several maneuvers during this period which required the spacecraft antenna to be moved away from the earth; therefore, 100 kW commanding was required as a contingency in the event the spacecraft sequence was not performed normally.

The spacecraft imaging requirements were such that a 44.8 kb/s data rate needed to be maintained for a major portion of the encounter period. This requirement was the driver for the major implementation improvements to the DSN antennas and the requirement for real-time arraying. The station support was complicated additionally by the need to switch data rates from 44.8 kb/s to 29.9 kb/s to 7.2 kb/s, etc. as many as 15 times during a pass.

The high-accuracy navigation requirements resulted in the DSN providing four different types of radio metric data for the Voyager encounter. These data types were a navigation cycle which required four continuous station passes in the following order: Australia, Spain, Goldstone, Australia. These navigation cycles included angle, doppler, and ranging measurements. Another data type used was near-simultaneous ranging, which required data gathering during the overlap of two of the DSN complexes. The third data type was short baseline ranging, which required simultaneous data gathering from two stations at one complex. The final data source which was developed on a best-effort basis for this encounter was delta differenced one-way ranging.

The Radio Science System was needed during the encounter phase to obtain solar conjunction information, celestial mechanics information, encounter radio science occultation information, and ring scattering information. The Radio Science detail configurations and objectives are provided in more detail in part D of this section.

The DSN stations planned support periods for the Saturn 1 encounter are summarized in Table 10-2.

The Goldstone DSSs 14 and 12 were arrayed daily to obtain Saturn imaging at 29.9 kb/s during the entire observatory phase. The other complexes only used one station for most of this period to guarantee obtaining the general science and engineering information.

At the beginning of the far-encounter phase, starting on 24 October and continuing through the early part of the post-encounter phase (Nov. 22), real-time arraying was required at all complexes to obtain high-rate imaging at 44.8 kb/s. The project desired to maintain the highest bit rate possible with good possibility of receipt on the ground. This necessitated both real-time arraying and considerable switching of data rates during the pass.

Figure 10-1 provides a typical station high-rate telemetry support profile during the intense image-gathering period at encounter.

Figure 10-2 reflects the telemetry link margins available at each of the complexes with and without arraying on near-encounter day.

A very intensive and comprehensive set of radio metric measurements using four different radio metric data types was used during the encounter period.

Figure 10-3 reflects the DSN radio metric data plan in support of trajectory correction maneuver A-8 and validation of that maneuver. Also provided as part of this table is the radio science solar conjunction measurements made on both Voyager 1 and Voyager 2.

Figure 10-4 reflects the comprehensive radio metric measurements taken near encounter which were used for the trajectory correction maneuver A-9 and its validation.

Table 10-2. DSN Support of Voyager 1 Saturn Encounter

Phase	Dates (1980)	Station coverage	Comments
Observatory	8-23 through 9-11	Goldstone arrayed plus other remaining 34-meter DSSs	DSSs 12, 14, 42, and 61
Movie	9-12 through 9-14	All complexes arrayed	All 64- and 34-meter stations
Observatory	9-15 through 9-28	Goldstone arrayed plus DSSs 43 and 61	Prime solar conjunction
Observatory	9-28 through 10-24	Goldstone arrayed plus other remaining 34-meter DSSs	64-meter stations replace 34-meter stations for navigation cycle
Far-encounter, Near-encounter, Post-encounter, plus 10 days	10-24 through 11-12 11-12 through 11-13 11-13 through 11-23	All 64- and 34-meter stations arrayed	All 64- and 34-meter stations
Post-encounter (10d to 30d)	11-23 through 12-19*	All 64- and 34-meter stations arrayed except DSS 63	DSSs 12, 14, 42, 43 and 61

*DSN supported 4 days longer than originally planned.

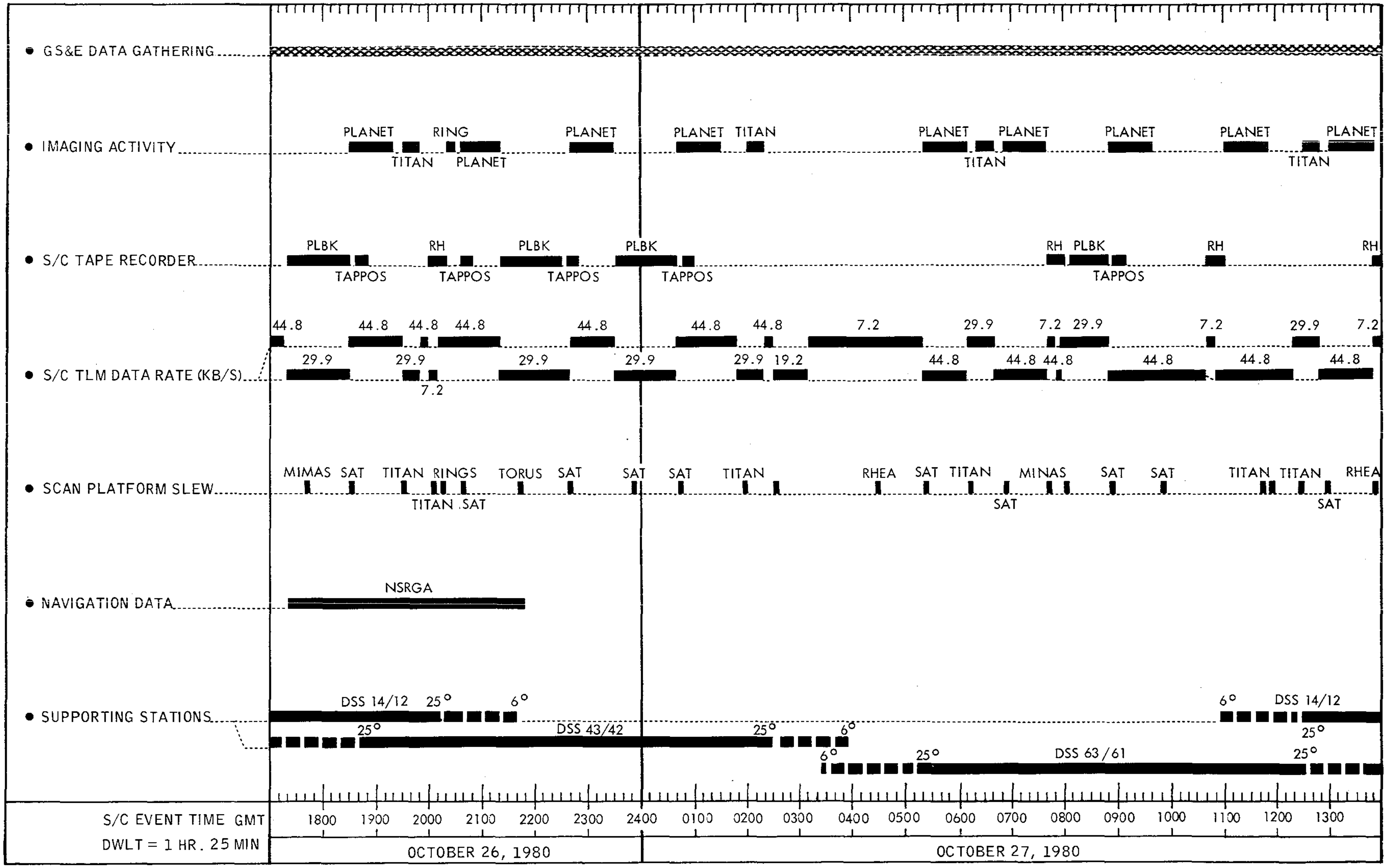


Figure 10-1. Typical Intensive High-Rate Telemetry Support

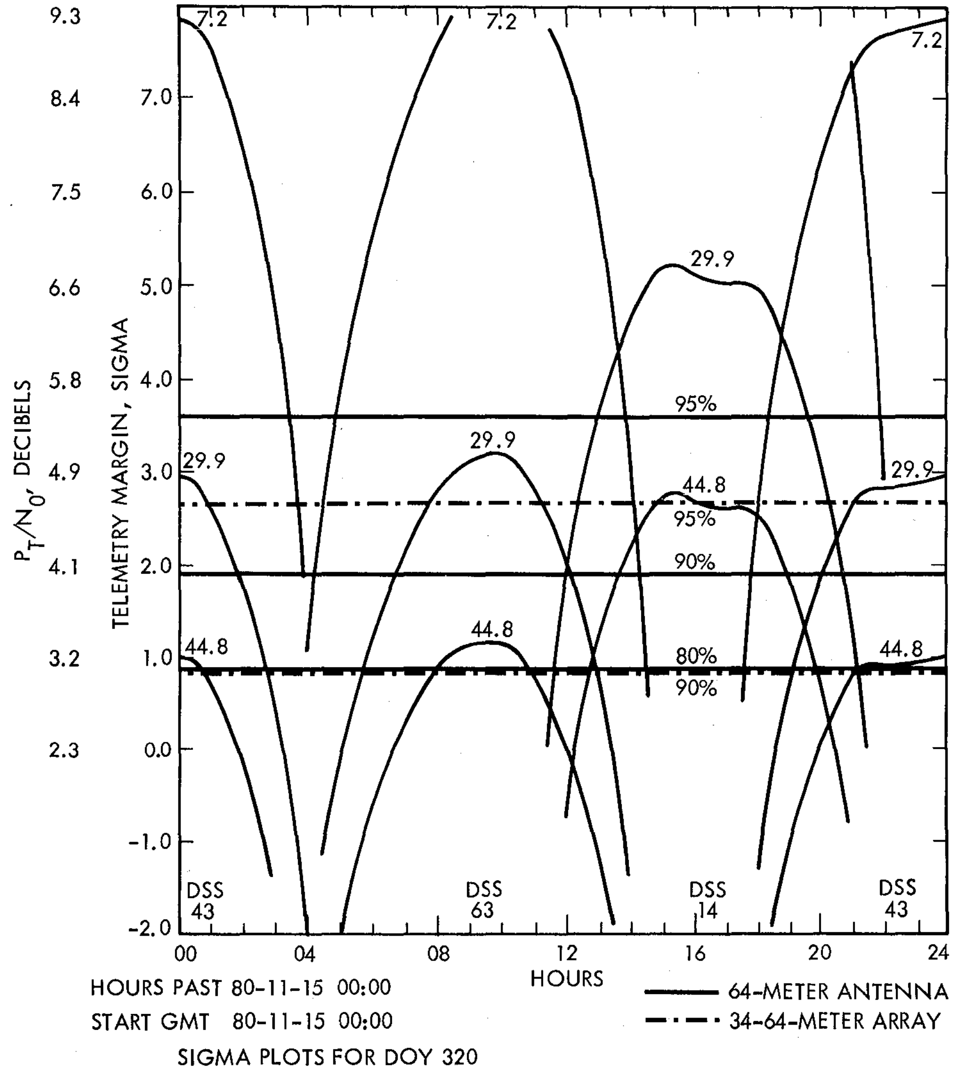


Figure 10-2. DSN Telemetry Link Margins for Voyager 1 Saturn Encounter

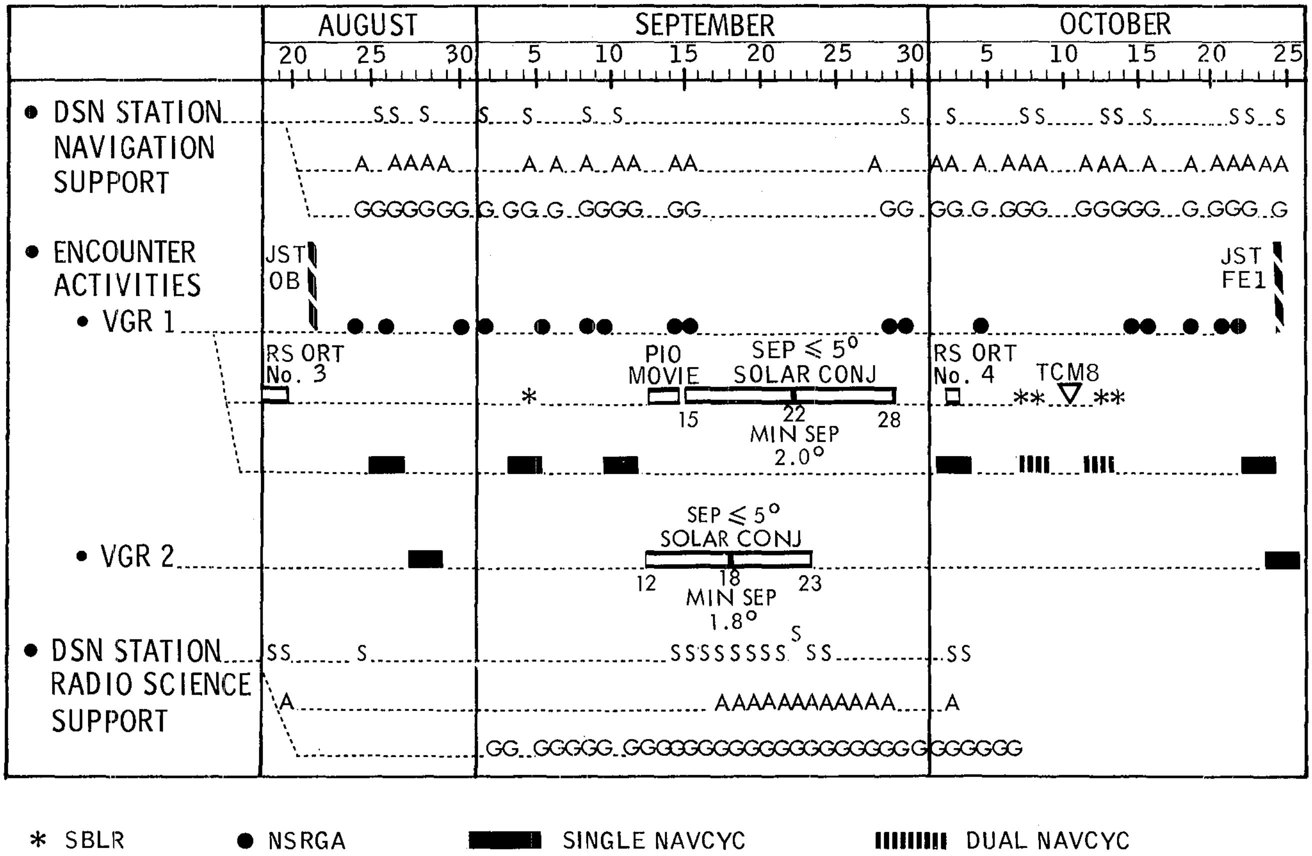
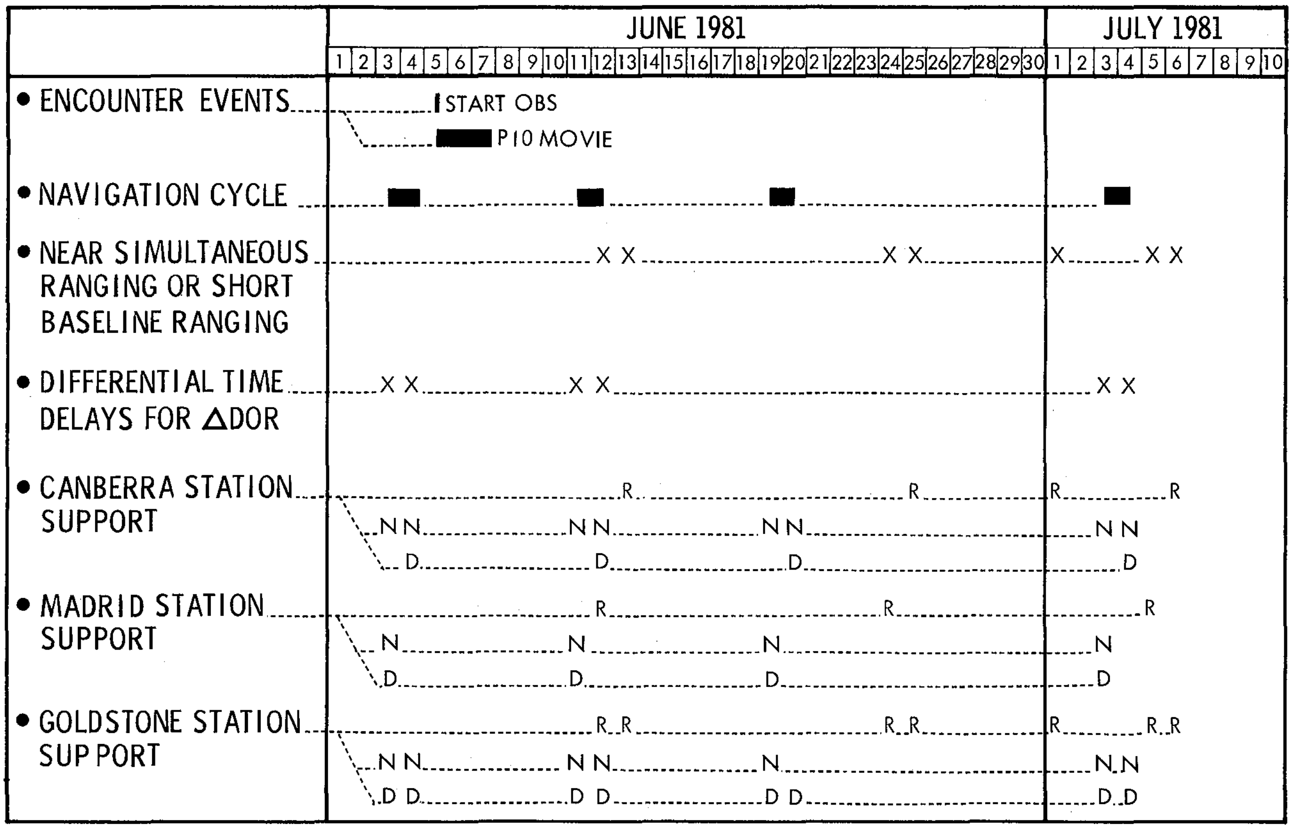


Figure 10-3. DSN Radio Metric and Solar Conjunction Support



KEY: X = EVENT WILL OCCUR ON THIS DAY
N = NAVIGATION CYCLE
D = DIFFERENTIAL TIME DELAY
R = NEAR SIMULTANEOUS RANGING
S = SHORT BASELINE RANGING

Figure 10-4. DSN Radio Metric Support for Voyager 1 Encounter

C. DSN OPERATIONS

1. Introduction

The DSN Operations support of the Voyager 1 Saturn encounter encompassed the following activities:

(1) General science and engineering telemetry data collection and distribution.

(2) Saturn and Saturn rings imaging telemetry data collection and distribution.

(3) Saturn satellite imaging telemetry data collection and distribution.

(4) Radio science data collection and distribution.

(5) Radio metric data generation and distribution.

(6) Very Long Baseline Interferometry System (VLBI) data generation and distribution.

(7) Monitor data generation and distribution.

(8) Transmission of spacecraft command data.

(9) Intermediate Data Record (IDR) generation.

(10) Data quality evaluations.

(11) Voice and data communications.

(12) Radio Science operations testing.

(13) Navigation cycles.

(14) Trajectory correction maneuvers.

(15) Horizontal and vertical scan maneuvers.

(16) Cyclic periods of Antenna Microwave Subsystem scan.

(17) Celestial mechanics.

To support the Voyager 1 requirements during the encounter phase, the DSN provided intensive and comprehensive support throughout the entire period. All complexes were used in the arrayed mode. Spacecraft imaging requirements were such that a 44.8 kb/s data rate was required for a major portion of the encounter period. General science and spacecraft engineering data were obtained continuously throughout the Voyager 1 Saturn encounter.

2. Observation Phase

A time-lapse movie was compiled from images taken during the period from 12 September to 14 September 1980. Images were taken every 4.8 minutes during four Saturn rotations and were transmitted in real-time, or during a playback period, to DSS 14. To obtain the telemetry data, including the images, the 34-meter and 64-meter networks were arrayed for the entire period. Overlapping the movie activity was the solar conjunction (3 September to 6 October 1980), when the sun was between the earth and the spacecraft. The smaller the sun-earth-probe angle, the greater the interference experienced by radio communications. However, the condition did allow study of the sun as the radio signal passed through the corona.

Although the noise was evident in some photographs, the movie requirement was met. Solar conjunction data were also collected from both Voyager 1 and Voyager 2 to complete the experiment data requirements.

A trajectory correction maneuver (A-8) was performed on 10 and 11 October 1980. The correction was to change the trajectory so that the spacecraft closest approach to the surface of the Saturnian satellite Titan would be 4600 km. Without the maneuver, there was the possibility of a collision with Titan.

The spacecraft was rolled 90 degrees and then turned through a yaw of 136.7 degrees to place it in the proper attitude for the motor burn. A burn of 806 seconds was executed to produce a change in velocity of 1.778 meters per second.

During the maneuver, the spacecraft downlink was lost during the positioning for the burn and reacquired afterward. The maneuver was supported by DSSs 61, 12, and 14. To provide a small margin of additional capability, the stations were instructed to put in the bypass to the antenna film-height detector. Under normal operations, when the antenna film-height detector senses a low film height, the antenna is automatically stopped. By placing the bypass IN, the operator will manually stop the antenna if the film-height detector alarm is activated for 15 seconds. By using this option, false alarms are reduced, and unnecessary data loss is avoided during critical data periods.

The fourth Radio Science System (RSS) Operational Readiness Test (ORT-4) was conducted on 2 and 3 October 1980. The test was to demonstrate (1) Occultation Data Assembly (ODA) medium-band S- and X-band and narrow-band S- and X-band data acquisition, (2) acquisition of radio science wideband backup data using the Digital Recorder Assembly (DRA), (3) capability of measuring and recording system temperatures in real-time, and (4) Spectral Signal Indicator (SSI) performance and utility for acquisition of occultation data. The ORT was conditionally successful although there were minor problems with the SSI and the DRA.

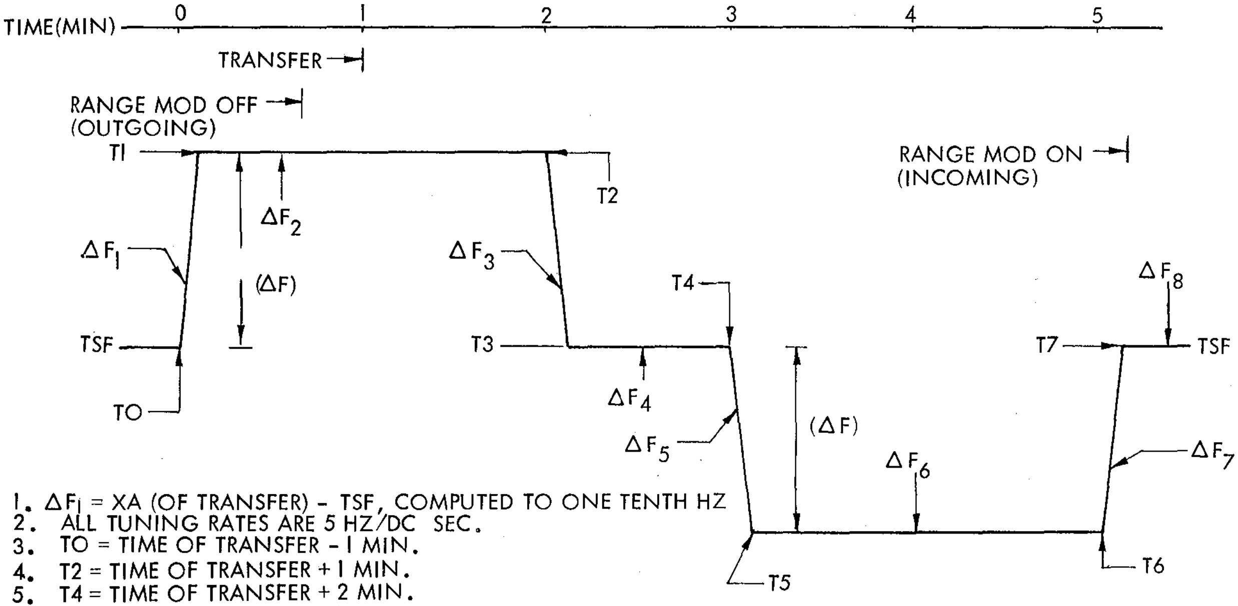
To resolve the problems encountered in ORT-4 and to increase the proficiency of the operation and support of the Radio Science System (RSS) effort, a series of 14 Operational Verification Tests (OVTs) was scheduled for DSSs 43 and 63. The results obtained from the OVTs increased efficiency and effectiveness, which became more evident with each succeeding test. Procedures for calibration and operation of the equipment were clarified and standardized as a product of the tests. By the end of October 1980, the RSS problems were mainly resolved and the System operations greatly improved.

3. Far-Encounter 1 Phase

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 orbit determination data in preparation for a final trajectory correction prior to closest approach to Titan. During this navigation cycle, all 34- and 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 DSSs 63 and 43 during their common view period. A unique geometry, zero declination, existed at Saturn encounter for Voyager 1. 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 transfers 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 was used. This procedure, upon completion of all required tuning, restored 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 10-5 depicts an NSR transfer and related events. It can be seen that the transfer required 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 track synthesizer frequency (TSF). Since the XA is a doppler-dependent frequency, it constantly changes; therefore, the frequency for any given tuning pattern is approximately five minutes.



1. ΔF_1 = XA (OF TRANSFER) - TSF, COMPUTED TO ONE TENTH HZ
2. ALL TUNING RATES ARE 5 HZ/DC SEC.
3. TO = TIME OF TRANSFER - 1 MIN.
4. T2 = TIME OF TRANSFER + 1 MIN.
5. T4 = TIME OF TRANSFER + 2 MIN.
6. T6 = TIME OF TRANSFER +4 MIN.
7. PRA MUST NOT BE INTERRUPTED REGARDLESS OF TRANSMITTER OR RANGE MOD STATUS.
8. DOPPLER SAMPLE INTERVAL = 10 SEC.
9. RECEIVER BANDWIDTHS SET 30 HZ-WIDE, NO TUNING AT TRANSFER REQUIRED.
10. TRANSFERS TO OCCUR ON 35 MIN CENTERS.

Figure 10-5. An NSR Transfer and Its Related Events

4. Far-Encounter 2 Phase

On 3 and 4 November 1980, the last Radio Science Operational Verification Tests were conducted with DSSs 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 representatives at DSSs 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, to interface with the RS Team, and 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 and idle modes.

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

On 5 November 1980, the RS ORT-5 was conducted with both DSS 43 and DSS 63. This ORT simulated the Saturn encounter operations 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 were declared ready for the occultation experiments.

On 6 November 1980, a trajectory correction maneuver (TCM-A9) was performed to refine the Titan flyby time of arrival and altitude at closest approach. The maneuver required the spacecraft to rotate off earth-point, resulting in a loss of the downlink. After 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.

During the period of 7 November through 10 November 1980, a post-TCM dual navigation cycle was supported to provide the new trajectory information for orbit determination. During this navigation cycle, NSR was 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- and 64-meter stations was likewise accomplished during their tracking periods. Optical navigation pictures to provide additional refinement were periodically received during the period.

On 10 November 1980, the spacecraft entered the encounter cyclic phase during which the telemetry formats and bit rates changed frequently. This mode of operation allowed several different imaging formats, playback of recorded data, and various general science formats to be transmitted in bit rates from 19.2 kb/s through 44.8 kb/s in rapid succession. This required the stations to be alert to the sequence and the requirement to reinitialize the TPAs for the bit rate changes to insure that the telemetry strings were locked up and good data were processed without undue delay. This mode of operations continued throughout the near-encounter period.

On 11 November 1980, with the acquisition of Voyager 1 by DSS 14, the requirement was imposed on the 64-meter network to count down 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 1980, with the conclusion of the DSS 14 tracking period. No problems were encountered that required the implementation of contingency plans.

On 11 November 1980, preparations began for the closest approach of Titan. One of the first actions was to reorient the spacecraft roll reference from Canopus to Miaplacidus to avoid obscuration of Titan. This reorientation was accomplished by a roll turn while completing fields and particles measurements. This maneuver required DSSs 14, 12, 43, and 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.

5. Near-Encounter

The radio science experiment with the Titan occultation was diametric 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 of 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 medium band, open-loop receiver in the two-channel configuration. Ionospheric data were obtained from the closed-loop Receiver-Exciter Subsystem. A signal profile was provided by the project, and during the operation it was found to be fairly accurate. See Subsection D of this section for detailed Radio Science support information.

6. Post-Encounter

On 22 and 23 November 1980, an ultraviolet vertical scan (UVS) 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 shortly after the predicted acquisition time. DSS 61 and DSS 12 were backup to DSS 14 and acquired the downlink at the predicted time.

Activities 23 November through 30 November 1980 settled into a routine of: (a) infrared interferometer spectrometer (IRIS) composition measurements, (b) radio emission studies, (c) plasma wave instability measurements, (d) celestial mechanics studies, (e) removal of residual measurements, (f) coverage of Saturn's illuminated crescent, (g) system scans of the intensity of emission from Titan's orbit, and (h) six-level system scan covering Titan's entire orbit. These data were received by the stations in either real-time or playback modes during the normal, scheduled tracking periods.

The post-encounter period was scheduled to end on 15 December 1980, but due to the unusual observations of the rings during the near-encounter, the post-encounter period was extended to 19 December 1980 so that another movie could be made.

The post-encounter support consisted primarily of the observations of Saturn's atmosphere at high phase angle over a long time base, periodic imaging of Saturn, and system scans at phase angles and latitudes different from those in the pre-encounter phases. Imaging data were returned at the higher data rates (29.8 kb/s and 44.8 kb/s) in the imaging formats. The system scan data were returned at the lower data rate (7.2 kb/s) in the general science format. DSS 14/12 and DSS 43/42, in the arrayed configuration, were scheduled to receive the imaging data, with DSS 61 or 63 scheduled to receive the general science data consistent with station view period.

The Saturn rings movie activity was conducted on 18 December 1980. DSSs 14, 42, 43, 61, and 63 supported the activity with the DSS 61/63 and the DSS 42/43 arrays enhancing image data reception. This activity completed the Voyager 1 Saturn encounter phase.

D. RADIO SCIENCE

1. Introduction

The Radio Science System for the Voyager 1 Saturn encounter was configured to support three different types of radio science.

The first radio science data type was solar conjunction information, which consisted of observing the change in the spacecraft signal propagation as it passed at a close sun-earth-probe angle.

The second radio science data type was celestial mechanics information obtained by observing changes in the radio metric doppler and ranging data as the spacecraft traversed the area of Saturn influence.

The third radio science data type consisted of near-encounter observations of Titan occultation, Saturn occultation, Saturn ring occultation, and a ring scattering measurement. The DSN equipment configuration to support these radio science encounter measurements was quite extensive, and considerable new implementation was required as indicated in A.4 of this section.

2. Solar Conjunction Support

Solar conjunction support was provided by the DSN to Voyager 1 from 15 September to 28 September with a minimum sun-earth-probe angle of two degrees occurring on 22 September 1980. Solar conjunction support on Voyager 2 occurred between 12 September and 23 September with a minumum sun-earth-probe angle of 1.8 degrees occurring on 18 September 1980.

3. Celestial Mechanics Support

The celestial mechanics support provided by the DSN was to allow radio science observations which would provide data on the gravity field of the planets, their rings, and their satellites. The DSN deliverable to the project was closed-loop doppler and ranging data. The celestial mechanics experiments are conducted by integrating into the spacecraft sequence the series of two-way noncoherent on and off commands so as to establish a desirable balance of one-way and two-way tracking data throughout the encounter period. Two satellites of particular interest for obtaining mass determinations were Rhea and Titan. Also, the dual frequency tracking data was used to characterize the Saturn system plasma environment. During the observatory phase in the far-encounter period, celestial mechanics data were obtained once per week from encounter minus 82 days to minus 71 days and then daily thereafter to encounter minus 10 days. The celestial mechanics measurements were continuous starting at encounter minus 10 days and continuing into encounter plus 10 days. The DSN data during the celestial mechanics experiments consisted of standard closed-loop radio metric tracking with special range parameters and doppler sample rates. These special parameters were specified by the project in an agreed-upon format in the time interval before the station track. The overall support provided by the DSN to the celestial mechanics experiment is discussed in Subsection C of this section. The overall support to celestial mechanics by the DSN was excellent with very few problems encountered in obtaining this data.

4. Encounter Radio Science

The DSN supported the Titan occultation with a medium-band configuration on 12 November 1980 from DSS 63. The following day, the Saturn occultation was supported by both DSS 43 and DSS 63, with DSS 43 in a narrowband radio science configuration and DSS 63 in a medium-band radio science configuration. DSS 63 also supported the ring occultation and ring scattering experiments in a medium-band radio science mode. All the radio science observations by DSS 63 were also recorded on a wideband Digital Recording Assembly.

The spacecraft was in a two-way noncoherent mode with telemetry modulation off and downlink signal being transmitted via the ultrastable oscillator. This maximized the downlink signal power and frequency stability.

The DSN Radio Science System configuration to support the Uranus encounter is provided as Figure 10-6.

The Radio Science System included not only a considerable amount of station equipment but also support from the Network Operations Control Center and the DSN Compatibility Test Area (CTA 21). The Network Operations Control Center provided radio science and tracking predicts and monitor and control data. It processed the monitor and control data and the incoming Spectral Signal Indicator data and provided displays to the project radio science area.

CTA 21 provided post-test processing of the Radio Science medium-band and wideband data from tapes received from DSS 63. The primary CTA 21 function was to reduce the bandwidth of the station Digital Recorder Assembly magnetic tapes and provide them to the project investigator in a computer-compatible format.

The DSN station support intervals for the near-encounter radio science are provided in Figure 10-7.

E. RELIABILITY AND DISCREPANCIES

In preparation for the Voyager 1 Saturn encounter, the DSN was required to accomplish extensive new implementation to meet project requirements and increase the reliability of the supporting systems to provide high-quality science data to the project. The implementation included the conversion of the 26-meter S-band antennas to 34-meter S- and X-band capability and the development and installation of state-of-the-art low-noise masers at all 64-meter deep space stations.

Only one significant problem occurred during the entire Voyager 1 Saturn encounter. Two of the state-of-the-art low noise masers failed, and the stations were required to fall back to the standard low-noise masers. This caused a loss of approximately 1 dB of equivalent received signal.

The encounter was highly successful and to a great degree was the result of both the implementation effort of the DSN and the operations support provided by both the DSS personnel and the DSN Operations personnel at JPL.

F. SUMMARY OF DSN HIGH-RATE IMAGING SUPPORT

The DSN supported the Voyager 1 Saturn encounter from 22 August through 16 December 1980. Table 10-3 indicates the Voyager general science and engineering and imaging data lost during high-rate imaging intervals. The table shows that most lost images were due to weather.

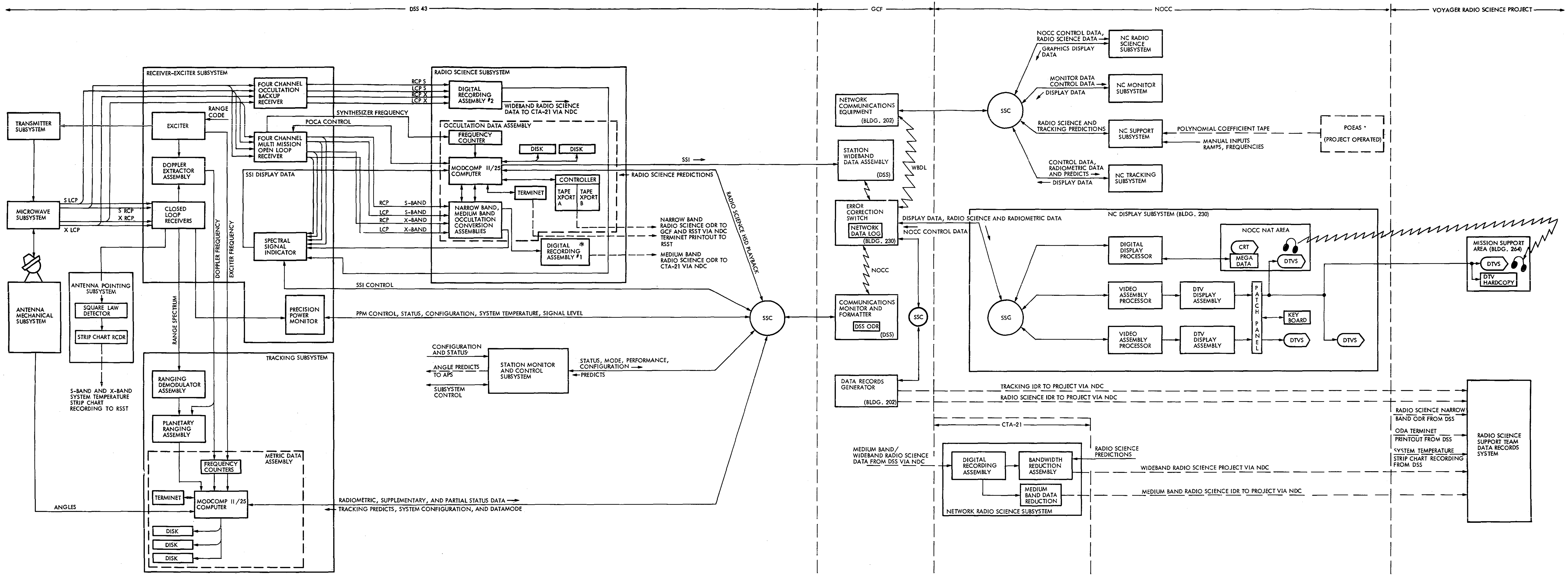


Figure 10-6. Voyager Radio Science System Detailed Planning Block Diagram for Voyager 1 Saturn Occultation

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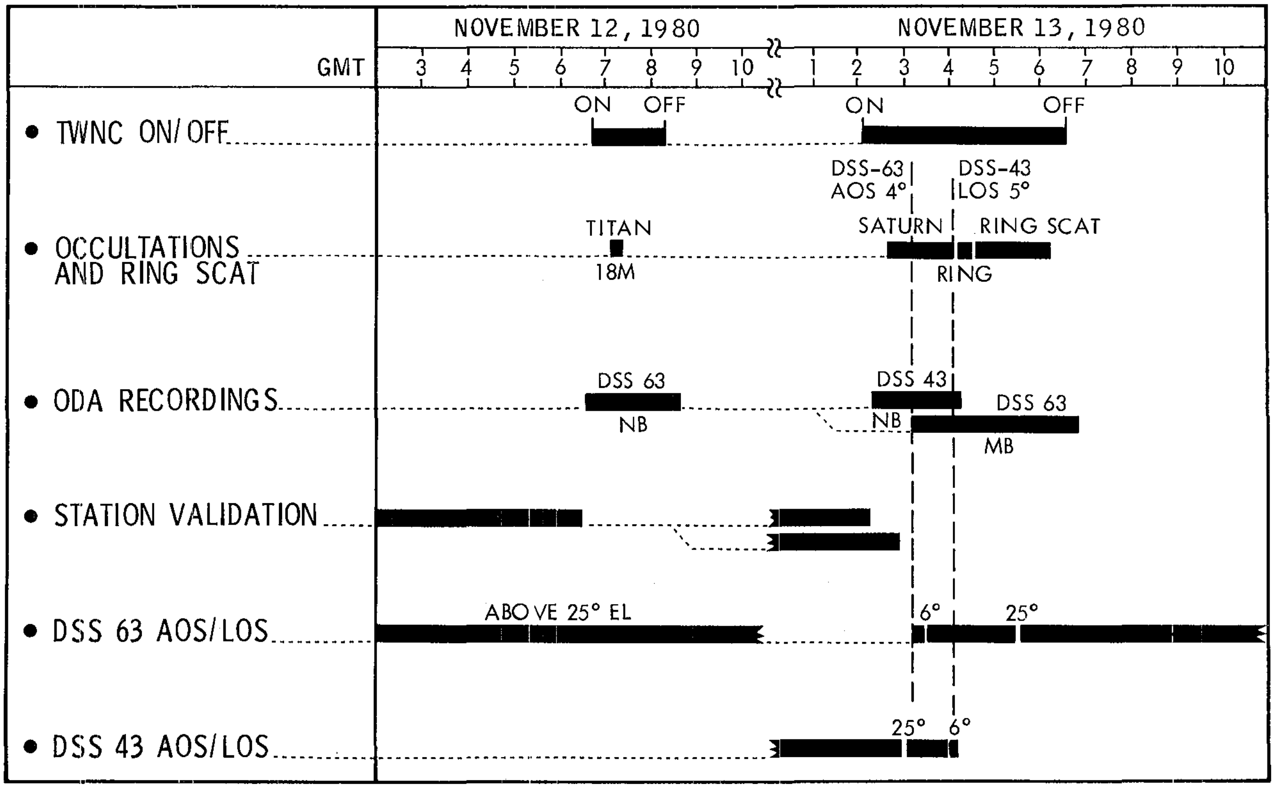


Figure 10-7. DSN Support of Voyager 1 Saturn Radio Science

Table 10-3. Voyager 1 Saturn Summary Imaging Results

Mission Phase	Dates of Phase	Total Imaging Frames	Imaging Frames Lost	Imaging Frames Degraded	Comments
Observatory	Aug. 23, 1980 through Oct. 24, 1980	4,202	6	5	
Far-encounter 1	Oct. 24, 1980 through Nov. 2, 1980	1,902	0	16	
Far-encounter 2	Nov. 2, 1980 through Nov. 12, 1980	2,651	6	118	4L[a] heavy rain, 97D[b] heavy rain, 19D wrong CMD suppression
Near encounter	Nov. 12, 1980 through Nov. 13, 1980	567	0	9	5D S/C in wide deadband
Post-encounter, encounter, through encounter + 6 d	Nov. 13, 1980 through Nov. 19, 1980	1,093	13	52	40D cloudy and rainy
Post-encounter, encounter + 6 d through encounter end	Nov. 19, 1980 through Dec. 19, 1980	6,653	19	69	8L heavy rain, 59D rain, 6L 14 power glitches, 4L Madrid XRO 2 maser red
Totals	Aug. 22, 1980 through Dec. 16, 1980	17,068	44	269	
Totals minus weather			32	73	12L weather-related 196D weather-related

[a] L = lost frame
[b] D = degraded frame

SECTION XI

VOYAGER 2 SATURN ENCOUNTER

A. DSN SPECIAL IMPLEMENTATION

1. Introduction

Between the Voyager 1 and Voyager 2 Saturn encounters, the DSN had only a limited period of time to do any additional implementation to the network. The months available were December 1980 through April 1981. Seven implementation tasks had to be completed to ensure the success of the Voyager 2 Saturn encounter. These tasks are summarized as follows:

(1) Metric Data Assembly software update for automatic uplink tuning.

(2) Radio Science equipment move from DSS 63 to DSS 43.

(3) Occultation Data Assembly software modification to allow wideband data transmission.

(4) Interface Precision Power Monitor noise-adding radiometers to the Radio Science Digital Recorder Assembly.

(5) Multimission Receiver synthesizer power supply upgrade.

(6) Improved medium band analog-to-digital (A-D) converters.

(7) High-reliability magnetic tapes for the Digital Recorder Assembly (DRA) (AMPEX 799 and 79A).

The last six items above are all modifications required to provide an adequate Radio Science System at DSS 43.

Several other DSN tasks were selected for implementation between the two encounters which would significantly enhance the DSN support provided. These enhancements are summarized as follows:

(1) A second X-band low-noise maser for each of the 64-meter antennas.

(2) DSS 12 antenna improvements.

(3) Ground Communications Facility reconfiguration task.

(4) The VLBI Block I phase-2 delta differenced one-way ranging.

2. Metric Data Assembly Software Update for Automatic Uplink Tuning.

The important Metric Data Assembly software modifications incorporated in this software update were all involved with automatic uplink tuning needed to operate with the degraded Voyager spacecraft receiver. The most important of these updates was the seven-point best-lock frequency automatic stepping and the improving of the interface with a new Digitally Controlled Oscillator (DCO).

3. Radio Science Equipment Move from DSS 63 to DSS 43

Much of the Radio Science equipment used at Madrid during the Voyager 1 Saturn encounter was needed in Australia during the Voyager 2 Saturn encounter, because the Saturn occultation and ring scattering occurred during the Australian view period. The equipment moved was the prime Radio Science Multimission Receiver and a backup four-channel Multimission Receiver. Also included was the Digital Recording Assembly, which consisted of two recorders and an interface control cabinet.

4. Occultation Data Assembly Software Modification and Precision Power Monitor Interface

The Occultation Data Assembly software was primarily modified to allow playback of narrow-band, medium-band, and Programmed Oscillator Control Assembly data over wideband data lines to JPL. This software was also modified to allow the noise-adding radiometer data from the Precision Power Monitor to be recorded on the Radio Science Digital Recorder Assembly. The Precision Power Monitor interface to the Digital Recorder Assembly consisted of taking the noise-adding radiometer inputs from the Precision Power Monitor and interfacing them with the Occultation Data Assembly. The Occultation Data Assembly software inserted this information on the correct channel of the Digital Recorder Assembly.

5. Multimission Receiver Synthesizer Power Supply Upgrade

Experience before and during the Saturn Voyager 1 encounter indicated that an undesirable 60-cycle noise was being generated by the data synthesizer associated with the Radio Science Multimission Receiver. Because of the limited time involved and the high cost of obtaining a major reduction in this noise, it was decided to evaluate the existing units in more detail. This evaluation showed that the amount of 60-cycle noise was somewhat dependent on the configuration and data synthesizer selected. All available data synthesizers which had been modified to provide external power supplies and whisper fans were tested and the two units which exhibited the least 60-cycle noise were selected.

6. Second X-Band Low-Noise Maser.

For the Voyager 1 Saturn encounter, one new state-of-the-art X-band low-noise maser was installed at each of the 64-meter sites, and a network spare was also available. The absence of spare low-noise masers proved to be a problem during the Voyager 1 Saturn encounter. During the first Saturn encounter, two of these masers failed, and the stations were required to fall back to the standard low-noise maser, causing a loss of approximately 1 dB of equivalent received signal. To improve the probability that the 64-meter antennas would have operational Block II masers for the Voyager 2 Saturn encounter period, an additional low-noise maser was fabricated and installed on the antenna at each 64-meter site.

7. DSS 12 Antenna Improvements

DSS 12 antenna gain was approximately 0.5 dB less than the other 34-meter antennas during the Voyager 1 Saturn encounter. Testing and measurements indicated that the DSS 12 antenna outer two rows of panels were warped and out of alignment. These panels had originally been installed as part of the 26-to-34-meter antenna upgrade. To remedy this situation, it was decided to replace the outer rows with new, better quality panels. Ninety-six panels in all were replaced and aligned. The implementation task was accomplished between 4 February and 26 March 1981, with final testing being completed by 10 April 1981.

8. Ground Communications Facility Reconfiguration Task

The Ground Communications Facility (GCF) undertook a major task to rearrange and reprogram the computers in the Central Communications Terminal and the Network Operations Control Center. The purpose of this task was to reduce the number of computers, improve Intermediate Data Record operation, and centralize overall GCF operations. The original time estimate for final equipment installation, subsystems testing, and operator training was three months. Unfortunately, several problems with the hardware, software, and interfaces caused the final operational date of this reconfiguration to be extended several months.

9. The VLBI Block I Facilities Delta Differenced One-Way Ranging

The Very Long Baseline Interferometry System was used on a best-efforts basis for the Voyager 1 Saturn encounter to obtain differential time delay to be used by the project for delta differenced one-way ranging. This task was to provide additional implementation of the VLBI to include an on-line correlation processing system, including on-line differential time delay processing. Upgrading the system was exceptionally important to the Voyager project because of the good experience they had with the delta differential one-way ranging measurements that were made during the first Saturn encounter.

B. DSN PLANNED SUPPORT

The Voyager 2 Saturn encounter period extended for 116 days, from 5 June 1981 through 25 September 1981. This encounter period was broken into several phases just like the Voyager 1 Saturn encounter period. These phases were observatory, far-encounter one, far-encounter two, near-encounter, and post-encounter. Table 11-1 summarizes the dates and key events during each of these encounter phases:

To support the many Voyager requirements during the encounter phase, the DSN again provided intensive and comprehensive support during the encounter period. All complexes were used in an arrayed mode daily from 31 July through 30 August. The same challenges of providing flawless commanding, near-continuous telemetry, several radio metric data types and comprehensive radio science support were again expected of the network.

The spacecraft imaging required 44.8 kb/s for a major portion of the encounter period. Other data returns used were 29.9 kb/s, 19.2 kb/s and 7.2 kb/s.

The navigation requirements of the project on the DSN were such that the same four radio metric data types used for Voyager 1 were again required to the same accuracies for Voyager 2. The navigation cycles, near-simultaneous ranging, and single baseline ranging data gathering were very similar to the support provided on the Voyager 1 Saturn encounter. The final data type, differential time delay, was provided on a near-real-time basis instead of on a several-day basis as provided on the Voyager 1 Saturn encounter.

The Radio Science System was used during the encounter phase to obtain celestial mechanics information, Saturn occultation data, and ring scattering information. The Radio Science detailed configuration and objectives are provided in more detail in Section D.

The DSN station planned support periods for Voyager 2 Saturn encounter are summarized in Table 11-2. DSS 61 and DSS 63 were arrayed daily for the last month of the observatory phase to obtain the daily Saturn, ring, and satellite imaging information at 29.9 kb/s. Starting on 31 July, at the beginning of the far-encounter phase, all DSN complexes provided daily 64-meter/34-meter arraying to obtain high-rate imaging at 44.8 kb/s. Arraying was also used to obtain data rates of 29.8 and 19.2 kb/s when the antenna elevation caused considerable loss in antenna gain.

A very comprehensive set of radio metric data measurements was obtained during the encounter period. The times these measurements were made, quantity of measurements, and stations obtaining the measurements are provided in Figure 11-1 for the observatory phase and for the trajectory correction maneuver B-8 and B-9 and near-encounter.

C. DSN OPERATIONS

1. Introduction

The DSN Operations support of the Voyager 2 Saturn encounter encompassed the following activities:

(1) General science and engineering telemetry data collection and distribution.

(2) Saturn and Saturn rings imaging telemetry data collection and distribution.

Table 11-1. Voyager 2 Saturn Encounter Mission Phases

Phase	Dates	Events
Observatory	June 5 through July 31	Daily general science and engineering data collection and daily selected Saturn and ring imaging. Saturn movie (June 5 through June 7). Trajectory correction maneuver B-8 (July 19).
Far-encounter 1	July 31 through August 11	Continuous general science and engineering data and near-continuous Saturn ring and satellite imaging.
Far-encounter 2	August 11 through August 25	Continuous general science and engineering data and near-continuous Saturn ring and satellite imaging. Trajectory correction maneuver B-9 (8/18). Saturn bow shock and magnetopause crossing.
Near-encounter	August 25 through August 27	High-quality Saturn satellite and ring imaging and science. Closest approach to Saturn, its rings, and satellites: Dione, Mimas, Enceladus, Tethys, and Rhea. Ring plane crossing, Saturn occultation, and Saturn ring experiment.
Post-encounter	August 27 through September 28	Daily Saturn and ring imaging and continuous general science and imaging data gathering. Imaging of Iapetus and Phoebe. Spacecraft health evaluation.

Table 11-2. DSN Planned Support of Voyager 2 Saturn Encounter

Phase	Dates (81)	Station Coverage	Comments
Observatory movie	6-5 through 6-7	All complexes arrayed	All 64- and 34-meter (4 rotations of Saturn)
Observatory	6-7 through 6-27	Madrid 64-meter plus DSSs 42 and 12	DSSs 63, 42, and 12
Observatory	6-28 through 7-31	Madrid arrayed plus DSSs 42 and 12	DSSs 63, 61, 42, and 12
Far-encounter, near-encounter, post-encounter plus 12 days	7-31 through 8-25 8-25 through 8-27 8-27 through 9-8	All 64- and 34-meter stations arrayed	All 64- and 34-meter DSSs
Post-encounter (12 d to 30 d)	9-8 through 9-28	Goldstone and Australian stations arrayed plus DSS 61	DSSs 12, 14, 42, 43, and 61

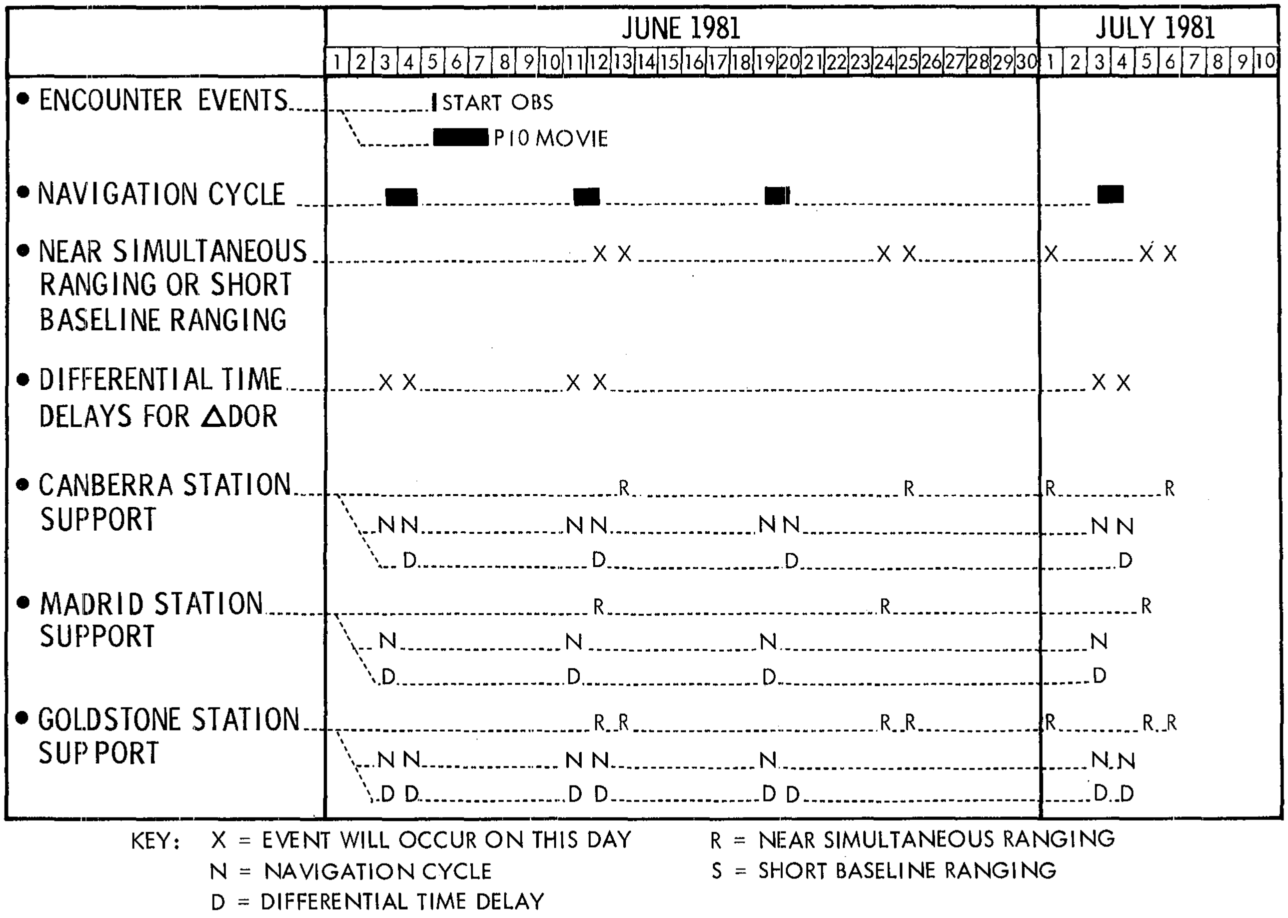
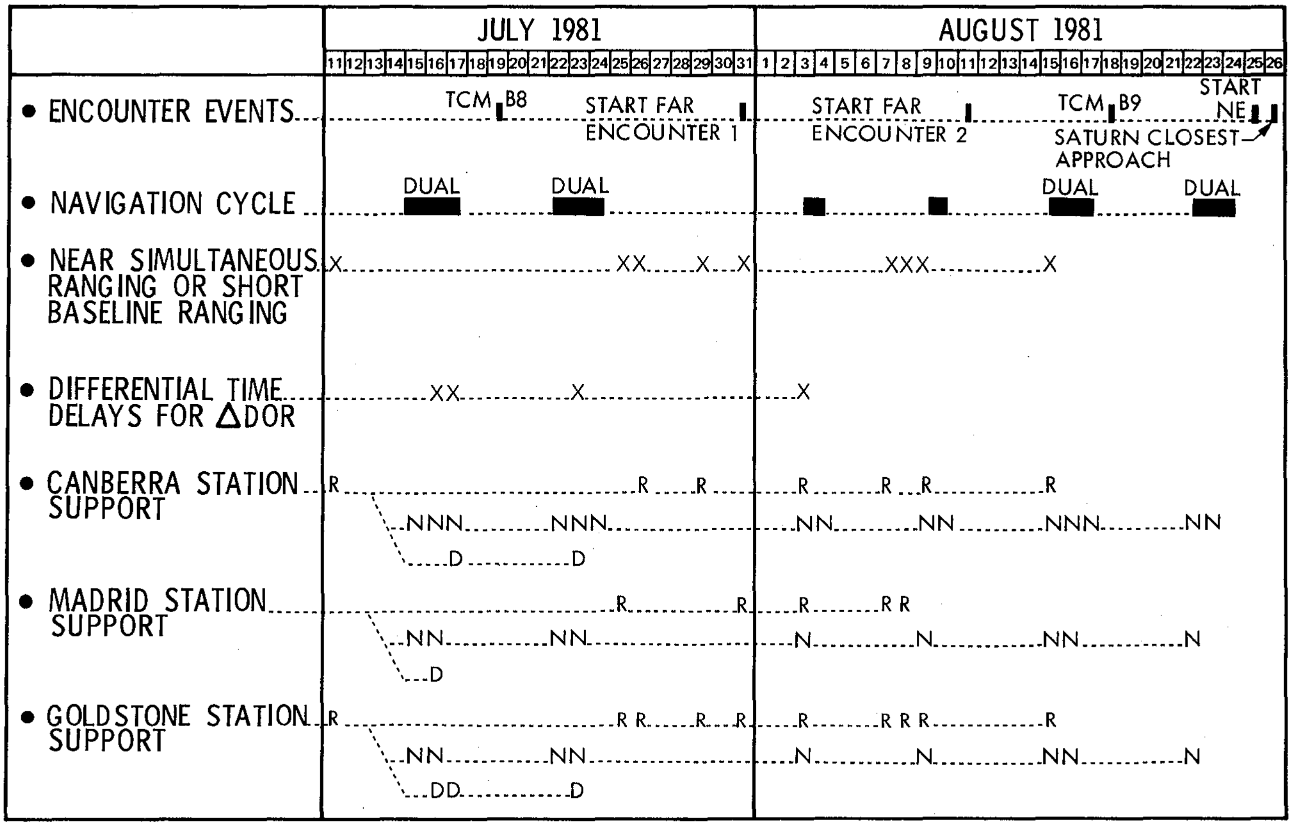


Figure 11-1. DSN Radio Metric Support of Voyager 2 Saturn Encounter



KEY: X = EVENT WILL OCCUR ON THIS DAY
N = NAVIGATION CYCLE
D = DIFFERENTIAL TIME DELAY
R = NEAR SIMULTANEOUS RANGING
S = SHORT BASELINE RANGING

Figure 11-1. (Cont'd)

(3) Saturn satellite imaging telemetry data collection and distribution.

(4) Radio science data collection and distribution.

(5) Radio metric data generation and distribution.

(6) Very Long Baseline Interferometry System (VLBI) data generation and distribution.

(7) Monitor data generation and distribution.

(8) Transmission of spacecraft command data.

(9) Intermediate Data Record (IDR) generation.

(10) Data quality evaluations.

(11) Voice and data communications.

(12) Radio Science operations testing.

(13) Navigation cycles.

(14) Trajectory correction maneuvers.

(15) Horizontal and vertical scan maneuvers.

(16) Cyclic periods of ultraviolet system scan.

(17) Celestial mechanics.

2. Observation Phase

The first activity of the observation phase of the Voyager 2 Saturn encounter was to complete a Saturn movie sequence. This activity started over DSS 61/63 and was concluded on 7 June 1981 over DSS 42/43. During the movie sequence, the arrayed (the 34-meter with the 64-meter) configuration was used at all deep space communications complexes (DSCCs) to enhance the received imaging telemetry data.

On 7 June 1981, Voyager 2 entered the preliminary observation routine of performing cyclic periods of ultraviolet system scan in real-time and recording Saturn zoom imaging data for spectral and dynamics studies. This activity was conducted during the view periods of DSS 42/43 and DSS 12/14. Playback of the spacecraft recorded imaging data occurred during the view period of DSS 61/63. Also, during the view period of DSS 61/63, interspersed multicolor imaging for long-time-base spectral dynamics studies was executed with the real-time telemetry data being received. This activity continued throughout the remainder of June 1981.

On 1 July 1981, a Radio Science Operational Readiness Test (ORT) was conducted with DSS 43. A command load was transmitted to the spacecraft to simulate the closest approach conditions and to exercise the Radio Science encounter sequence. Procedures and end-to-end operations of the support systems were validated. The test was successful as all major objectives were accomplished. Some minor problems were identified and corrected.

On 5 August 1981, a Radio Science mini-ORT was conducted to test the support systems following the corrective actions taken as the result of the problems identified during the ORT conducted on 1 July 1981. The test verified that the proper corrective actions had been accomplished.

During the observatory phase, DSS 43 Radio Science capabilities were exercised by conducting five Operational Verification Tests (OVTs). The primary objectives of these tests were to ensure that the equipment remained operational, configurations were valid, and personnel were trained and ready to support the Radio Science activity during the Saturn closest approach. Although minor problems were experienced during the testing, the conclusion was that the equipment and personnel were prepared to support the actual encounter operations.

On 19 July 1981, a trajectory correction maneuver (B-8) was performed by Voyager 2. The purpose of the maneuver was to position the spacecraft at a point approximately 161,000 km from the center of the planet at the time of Saturn closest approach. The maneuver was executed by roll and yaw turns, which placed the spacecraft in the proper attitude for the motor burn. This resulted in the spacecraft being placed off earth-point for two hours and 38 minutes, during which time no downlink was obtained.

DSS 12/42 supported the pre-burn activity, which included the transmission of fine parameter-adjust and maneuver-enable commands. The roll and yaw turns were executed over DSS 42, and loss of the downlink was observed as predicted. The burn occurred during the DSS 61/63 view period. The burn was accomplished, and the spacecraft returned to earth-point as programmed.

To assist in the reacquisition of the X-band downlink, DSS 63 had initialized the Occultation Data Assembly (ODA) and the Spectral Signal Indicator (SSI) to search the spectrum for first indication of the signal. The signal was observed by both the SSI and the X-band receiver, and DSS 61/63 reacquired the downlink telemetry at the predicted time.

Critical commanding followed the reacquisition of the spacecraft downlink to disable the maneuver recovery block (MRB). The MRB had been loaded into the onboard computer for execution should there have been an anomaly during the maneuver which would preclude reacquisition of the downlink signal.

The purpose of the MRB was to allow plotting of the downlink signal strength for determination of spacecraft pointing, in the case of an anomaly, by commanding the spacecraft to perform a 360-degree roll. To support this activity, DSS 63 had counted down the 100 kW transmitter for use should the MRB be executed and the extra uplink power be required to command the spacecraft through the low-gain antenna.

The commanding required to disable the MRB maneuver had to be accomplished within a limited command window. To accomplish the commanding, DSS 63 was required to establish an uplink ramp that would cross through the bandpass of the spacecraft receiver. The commands were timed to be transmitted so as to be received at the spacecraft during the period when the uplink was predicted to be within the receiver bandpass. This action was necessary because of the earlier failure of the tracking loop capacitor on the Voyager 2 spacecraft. This failure reduced the receiver bandpass and allowed the receiver frequency to have unpredictable variations with changes in the compartment temperature. During the period that DSS 63 was ramping the uplink, 30 MRB disable commands were transmitted on one-minute centers. The DSS 61 uplink was also ramping, with the transmitter off, as a backup to DSS 63. The DSS 63 Command System alarm went off and the transmitter and command systems at DSS 61 were turned on immediately. Commanding continued five minutes later. The commands were received by the spacecraft, and the MRB was disabled. This emergency procedure is documented and was used to support all spacecraft maneuvers.

Dual navigation cycles were supported by the network of 34- 64-meter arrays preceding and following the trajectory correction maneuver to provide verification of the results of the burn. Dual navigation cycles with near-simultaneous ranging were required to resolve the declination angles. The doppler technique is not adequate when a near-zero degree declination is approached. During a dual navigation cycle, seven station tracks were provided. The navigation cycles began in Australia (southern hemisphere) and continued with Spain and the United States (northern hemisphere). The Australian stations supported the first, middle, and last tracks of the cycle. This provided three southern and four northern tracks per cycle.

Three standard navigation cycles, which are composed of four tracks starting with Australia, were supported to provide the Project Navigation Team updated data for orbit determination. During processing of the navigation cycle range data, it was discovered that the DSS 43 data had a one-second timing bias. It was necessary for the Project Navigation Team to compensate for the error during processing. The range data from DSS 14 and DSS 63, as well as the doppler data from all three stations, were good and met Project requirements.

3. Far-Encounter 1 Phase

The far-encounter 1 phase began on 31 July 1981. The imaging data received in real-time and during playback were of excellent quality.

Horizontal and vertical scan maneuvers were conducted on 31 July and 1 August 1981. The purpose of these maneuvers was to align the ultraviolet scan field in a vertical position with respect to Saturn, allowing maximum resolution in the horizontal direction as defined by Titan's orbit, and then in the horizontal position for the same purpose, but in the vertical direction. The scan platform made a series of slews in each position to scan across the Saturnian system to study the atmospheric emissions.

The horizontal maneuver was supported by DSS 63/61, and the spacecraft stayed on earth-point during the maneuver. Telemetry data were received by the station throughout the period.

During the vertical maneuver, the spacecraft was off earth-point for six and a half hours. The period up to the loss of the downlink was supported by DSS 14/12, and the reacquisition of the telemetry downlink was supported by DSS 43/42. Included in the DSS 43/42 track was the maneuver recovery block no-operations (NO-OP) activity. This activity was the same as that performed following TCM B-8 discussed in the observatory phase. The inhibiting of the MRB command was successfully accomplished by DSS 43, and the backup capability of DSS 42 was not required.

4. Far-Encounter 2 Phase

During the far-encounter 2 phase of the Saturn encounter, continuous general science and engineering telemetry data and near-continuous Saturn ring and satellite imaging data were obtained. Saturn bow shock crossing and magnetopause data were obtained.

On 13 August 1981, a series of ring images was taken during the DSS 63/61 pass. The ring imaging activity continued around the network. The images were used to produce a ring movie under better lighting and approach conditions than those obtained during the Voyager 1 approach. The sequence was scheduled to cover a period of 31 hours and 42 minutes, including the playback period. The 34- and 64-meter stations were arrayed for this series of activities. Real-time data were received at 44.8 kb/s and the required playback data at a rate of 29.8 kb/s. Dual digital original data records (DODRs) were produced by all 64-meter stations during the taking of the ring images to ensure maximum data return. The sequence was completed, and the images were considered to be of excellent quality.

The final pre-encounter TCM (B-9) was successfully conducted on 18 August 1981. The maneuver was required to correct the incoming trajectory to acquire the desired time and altitude of the spacecraft closest approach to Saturn. A 1.018-meter-per-second change in spacecraft velocity was required to obtain the target requirements. The velocity change requirement was accomplished by a 380-second motor burn. The spacecraft performed a roll and yaw turn to place it in the correct position for the burn. The spacecraft went off earth-point, and the downlink was lost for one hour and seventeen minutes. DSS 14 reacquired the downlink at the predicted time. Data evaluation indicated that the maneuver was successful. This was also confirmed by comparison of the orbit determination data taken during the navigation cycles conducted prior to and following the maneuver.

On 19 and 20 August 1981, the final Radio Science Operational Readiness Test was conducted with support by DSS 43. All of the required Radio Science equipment had been installed and was operational. The finalized encounter sequence was used for the test. The test was successfully supported by the station, and the DSN was declared ready for the Saturn encounter.

5. Saturn Near-Encounter

The near-encounter mission phase began on 25 August 1981. During this period, continuous general science and engineering telemetry data and high-quality Saturn satellite and ring imaging data were obtained.

The recording of celestial mechanics data, which started on 15 August, continued through the near-encounter period. Gravity fields of the planet, rings, and satellites were mapped as well as data on gravitational red shift and ultrastable frequency stability. The 64- 34-meter networks supported this activity in the arrayed configuration, with data being successfully recorded at the 64-meter stations utilizing closed-loop doppler and range tracking.

The Radio Science near-encounter Saturn occultation data and ring scattering data were recorded by DSS 43 utilizing both the open-loop (medium band) wideband backup and the closed-loop receiver systems. The data consisted of Saturn atmospheric and ionospheric information and microwave scattering properties of the rings at oblique angles. See Subsection D of this Section for a detailed description of DSN support of the near-encounter Radio Science.

High-rate imaging data of Saturn and several of its satellites were successfully obtained by the DSN during closest approach. The majority of these images were obtained with the narrow-angle camera at 44.8 kb/s.

Concurrent with the imaging and Radio Science operations, the spacecraft was maneuvered so that the directional properties of the plasma fields and particles in the near-Saturn environment could be characterized. The maneuvers were also structured to accomplish other goals such as establishing Miaplacidus as a roll reference star, aligning the scan platform to obtain dark and bright limb observations, F-ring imagery, limb tracking, Vega acquisition (as a roll reference), and alignment of the spacecraft yaw axis with the Saturnian rotational axis to obtain information on plasma flow and particle fluxes in a direction other than those normally viewed. These activities were sequenced throughout the closest approach period. All were successfully supported by the 64- 34-meter DSS arrays.

The DSN support of the near-encounter operations was accomplished without any significant problems. In addition to the normal science DODRs provided by the 64-meter stations, a backup DODR was provided by both the 64- and 34-meter stations. During the closest approach, DSS 43 generated 10 medium-band and 40 wideband Radio Science DODRs.

Image data reception in the arrayed configuration was of excellent quality, and no images were lost due to DSN operations. Playback of the image data recorded during occultation was accomplished as scheduled.

Following the execution of the near-encounter activities and the exit from Saturn occultation, it was discovered that the spacecraft scan platform was stationary in a position away from the desired pointing. Only black sky image frames were being received. The project went into a troubleshooting and investigation mode, and the DSN geared for schedule and sequence of events (SOE) changes in support of the special project activities. The last, planned maneuver sequence was cancelled, and the first post-images were not received.

Initially, the scan platform position was determined, and limited changes in elevation and azimuth were attempted. It was determined that the changes in elevation were normal, but the changes in azimuth were erratic and slow in one direction and less so in the other direction. Playback of spacecraft recorded data indicated that the scan platform had functioned properly while the spacecraft was occulted and had faulted just prior to exit occultation. The platform was repositioned through a short series of stepped moves so that the camera was pointed at Saturn as the spacecraft continued away from the planet. Ring images were received in this mode. Although it was not the planned sequence, the data were deemed satisfactory. The DSN supported this entire nonstandard period with no significant problems.

6. Post-Encounter Phase

One of the primary post-encounter mission objectives was to obtain pictures of the satellite Phoebe. Rather than make the normal, extensive movements of the scan platform alone, it was decided to maneuver the spacecraft to star reference Canopus and make minor stepped movements of the scan platform to center Phoebe in the camera field of view.

The Phoebe movie sequence was completed successfully in this mode with supporting DSN stations providing excellent data reception. At the completion of the image sequence, the spacecraft was maneuvered again to the star reference Miaplacidus and the scan platform stepped to a safe position. During the spacecraft maneuver, the supporting DSN stations were required to configure for a ramp commanding operation for the maneuver recovery block NO-OP sequence. The ramp commanding was successfully executed by the DSN.

DSS 43 was required to make duplicates of the medium-band Digital Original Data Records (DODRs) of the Saturn occultation data. These duplicates were used to produce Intermediate Data Records (IDRs) for Radio Science processing. The original DODRs were held at the station for further use, in accordance with the Radio Science Operations Plan.

D. RADIO SCIENCE

1. Introduction

Exciting radio science was again planned for the Voyager 2 Saturn encounter. This radio science consisted of celestial mechanics measurements, Saturn occultation measurements, and ring scattering information.

The celestial mechanics measurements provided information which allowed mapping of gravity fields of the planet, rings, and satellites. The DSN system used to provide this information was the closed-loop doppler and ranging system at each of the DSN complexes. The Saturn occultation measurements were obtained using both the closed-loop telemetry data and the open-loop medium-band data from the DSN Radio Science system. Several Radio Science System reconfigurations had to be accomplished between the two encounters to provide the appropriate Radio Science System configuration at the Australian 64-meter station. This allowed the Saturn occultation and ring scattering measurements. The DSN Radio Science implementation to allow the improved configuration is described in Subsection A of this Section.

One of the problems uncovered during the Voyager 1 Saturn radio science data analysis was that the magnetic tapes used on both the medium-band and wideband recorders were of insufficient quality. Analysis showed that the bit error rates were, on the average, at least a factor of 10 more than desired. This was attributed to two factors. The first was insufficient screening of the tapes to be used for this purpose. The other was the environmental control of the tapes before, during, and after the recording period. A corrective action was taken, and special very-high-quality Ampex 799 and 79A tapes were purchased for use on the second encounter. Also, procedures were set up to control the environment of the tapes to be used. The primary environmental controls were humidity and temperature.

2. Celestial Mechanics Support

The DSN provided doppler and ranging information throughout the encounter period, which provided data on the gravity field of the planet, its rings, and satellites. The one-way doppler data were used to measure the red shift caused by placing the ultrastable oscillator (USO) in a Saturn gravitational field to determine the effect of Saturn's radiation environment on the USO. These data were also used to generate a USO frequency stability data base required for an analysis of radio occultation data.

The two-way ranging and three-way tracking data were used to investigate the gravity fields of Saturn, its satellites, and its rings by examining their effect on the spacecraft trajectory. For this encounter, the two-way ranging and three-way tracking data provided significant improvements on the Tethys and Iapetus mass determinations. The DSN celestial mechanics measurements were taken once a week from encounter minus 82 days to encounter minus 38 days. The celestial mechanics measurements after that period were increased to at least once per day from encounter minus 38 days to encounter plus 10 days. The support provided to the celestial mechanics measurements by the DSN was excellent throughout the entire encounter period.

3. Saturn Occultation

The Saturn radio science occultation began approximately 36 minutes after the closest approach of Saturn and lasted for about 95 minutes. The spacecraft performed limb-tracking maneuvers for the first five minutes and the last seven minutes of the occultation period. The Voyager 1 Saturn occultation measurements revealed the existence of strong radio absorbers at about 1.4 bars. This information allowed the design of the Voyager 2 limb-tracking maneuvers to obtain dual frequency data to a depth of at least 2 bars. The Saturn occultation measurements were provided from the Radio Science equipment at the 64-meter station. The 26-meter station provided S-band, closed-loop occultation backup coverage. The 34-meter station performed dual frequency, closed-loop tracking of Voyager 1 to obtain independent measurements of the solar plasma. These measurements were used to help calibrate the Saturn occultation data.

4. Ring Scattering Experiment

The DSN used the medium-band and wideband Radio Science System at the Australian 64-meter station to gather ring scattering measurements of the Saturn rings. The ring scattering experiment was conducted for a period of approximately 25 minutes immediately before the atmospheric occultation exit measurements. Both the ring occultation and ring scattering measurements occurred on 26 August 1981. The DSN closed-loop and open-loop Radio Science configurations used for the Saturn occultation and ring scattering experiment were essentially the same as the configuration in Spain during the Voyager 1 Saturn encounter. A block diagram of this configuration is provided as Figure 10-6 in Section X of this document.

CTA 21 processed both the medium-band and wideband radio science tapes which contained the Saturn occultation and ring scattering information. The CTA 21 processing function was to provide bandwidth reduction of the station Digital Recorder Assembly tapes to a project computer-compatible tape format. A simplified block diagram of this process is also provided in Figure 10-6.

Voyager 2 obtained higher resolution of the sizes and densities of the rings by using photopolarimeter and ultraviolet observations of the star Delti Scorpii occulted by the rings.

E. RELIABILITY AND DISCREPANCIES

The installation of low-noise masers at all 64-meter deep space stations and the rework of the 34- and 64-meter antennas to provide an improvement in antenna gain were completed prior to the Voyager 2 Saturn encounter. These improvements were largely responsible for the acquisition of the excellent-quality imaging data during the encounter period.

All of the events described in Subsection C of Section II, "DSN Operations", were accomplished in spite of the Voyager 2 spacecraft radio and scan platform problems, which placed additional requirements on the DSN.

Only minor data losses occurred during the 116 days of intense Voyager 2 encounter operations support. Most of these data losses were attributed to weather conditions, which were beyond the control of the DSN.

1. Observatory Phase

Minor problems occurred during the Radio Science Operational Readiness Test, which was conducted on 1 July 1981, but the test was considered successful. The problems and procedures were corrected and a mini-ORT conducted on 5 August 1981, which verified that the proper corrective action had been taken. The test was successful, and the system and personnel were declared ready to support encounter operations.

On 19 July 1981, the DSS 63 Command System alarm went off during a maneuver recovery block inhibit activity. The DSN has a standard emergency backup procedure that requires the 34-meter station to be on line, but with the transmitter off. DSS 61, therefore, turned the transmitter on and, within five minutes, continued the command sequence. The MRB was inhibited within the allowable command window.

2. Far-Encounter 1 Phase

During the far-encounter 1 period there was only one DSN problem which caused a loss of data. DSS 14 had an antenna sole plate problem in the hydrostatic bearing which caused a loss of eleven minutes of ultraviolet spectrometer mosaic data of Saturn.

Other data losses during this period were because of weather conditions, which are beyond the control of DSN Operations. DSS 12 experienced a hailstorm that ruptured the mylar shield on the S-band horn but had no significant impact on the Voyager project. Adverse weather conditions during a DSS 43 pass caused the loss of four images, severe degradation of six images, and moderate degradation of 27 images.

3. Far-Encounter 2 Phase

No significant DSN problems occurred during the far-encounter 2 phase. During this period, a series of ring images was obtained, and the final pre-encounter trajectory correction maneuver (TCM B-9) and Radio Science Operational Readiness Test (B-3) were conducted.

4. Near-Encounter

No significant DSN problems occurred during the near-encounter period.

5. Post-Encounter

Although additional requirements were placed on the DSN due to the malfunction of the spacecraft scan platform, the DSN had no significant problems in accomplishing the modified sequence. On 9 September 1981, the DSS 14 hydrostatic bearing runner joints failed, and DSS 14 was unable to move the antenna to point for support of the Voyager 2 pass. This required rescheduling of DSN support while DSS 14 was down for hydrostatic bearing runner repairs. DSS 12 and 13 were primarily used to support the Voyager requirements, causing a minimum of impact to the Voyager and other projects.

The hydrostatic bearing runner joints were repaired, and DSS 14 was able to resume normal tracking operations on 25 September 1981.

F. SUMMARY OF DSN HIGH-RATE IMAGING SUPPORT

The DSN supported the Voyager 2 Saturn encounter from 5 June through 25 September 1981. The general science and engineering and imaging support overall was excellent and compared very well with the Voyager 1 Saturn encounter support. Table 11-3 provides a summary of the high-rate imaging support provided by the DSN.

Table 11-3. Voyager 2 High-Rate Imaging Support

Event	Spacecraft Voyager 2	 Voyager 1
Total images shuttered	11,965	17,068
Total images lost	34	44
Total images degraded	111[a]	269
Individual station images lost		
Spain DSS 63	20[b]	
Australia DSS 43	10	
Goldstone DSS 14	4	

[a] Two-thirds of the degraded pictures were caused by three heavy rainstorms in Australia.

[b] Provided most of the high-rate imaging support during the observatory phase.

SECTION XII

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APPENDIX

GLOSSARY OF ABBREVIATIONS

AACS	attitude and articulation control subsystem
ACE	Voyager Mission Operations Controller
A-D	analog-to-digital
AFETR	Air Force Eastern Test Range
AGC	automatic gain control
AOS	acquisition of signal
APS	Antenna Pointing Subsystem
ARIA	Advanced Range Instrumentation Aircraft
ASCAL	antenna and sun sensor calibration
BLF	best-lock frequency
CCS	computer command subsystem
CCT	computer-compatible tapes
CDU	command detector unit
CMD	Command System (DSN)
CMF	Communications Monitor and Formatter Assembly
CONSCAN	conical scanning
CPA	Command Processor Assembly
CRSMVR	cruise science maneuver
CTA 21	Compatibility Test Area 21
CVT	Configuration Verification Test
dBm	decibel referred to one milliwatt
DCO	digitally controlled oscillator
DECOM	decommutator
DEIVT	DSE External Interface Verification Test

delta DOR	delta differential one-way ranging
DFT	Data Flow Test
DIS	Digital Instrumentation Assembly
DOD	Department of Defense
DODR	digital original data records
DRA	Digital Recorder Assembly
DRS	Radio Science Subsystem (DSS)
DRVID	differenced range versus integrated doppler
DSE	Department of Science and Environment (Australia)
DSN	Deep Space Network
DSS	Deep Space Station
ETR	Eastern Test Range (short for AFETR)
FDS	Flight Data Subsystem
FPGP	Fast Phi-Factor Generation Program
GCF	Ground Communications Facility
GDS	Ground Data System
GEOS	geodetic earth-orbiting satellite
GMT	Greenwich Mean Time
GSFC	Goddard Space Flight Center (Greenbelt, Maryland)
GSOC	German Space Operations Center
GYCAL	gyroscope calibration
HA	hour angle
HGA	high-gain antenna
HSDL	high-speed data line
IDR	Intermediate Data Record
IRIS	infrared interferometer spectrometer
IRV	interrange vector

JPL	Jet Propulsion Laboratory
KSC	Kennedy Space Center (NASA, Merritt Island, Florida)
L	launch
LECP	low-energy charged particle subsystem
LGA	low-gain antenna
LOS	loss of signal
MAPS	maneuver analysis program set
MCCC	Mission Control and Computing Center (JPL)
MCD	Maximum Likelihood Convolutional Decoder Assembly
MCT	Mission Configuration Test
MDA	Metric Data Assembly
MDS	Mark III - DSN Data Subsystems Implementation Project
MECO	main engine cutoff
MEIVT	MCCC Engineering Interface Verification Test
MES	main engine start
MIL 71	KSC, Merritt Island, Florida, DSN equipment configuration of NASA STDN Station
MM	mission module
MMA	Meteorological Monitoring Assembly
MMR	Multimission Open-Loop Receiver Assembly
MOCT	MCCC Operations Control Team
MOS	Mission Operations System
MRB	maneuver recovery block
MWBDL	multiple wideband data line
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications
NAT	Network Analysis Team
NAT CMD	Network Analysis Team Command

NDPA	Network Data Processing Area
NDPT	Network Data Processing Terminal
NEPN	Near-Earth Phase Network
NOA	Network Operations Analyst
NOC	Network Operations Chief
NOC	Network Operations Control
NOCA	Network Operations Control Area
NOCC	Network Operations Control Center
NOCT	Network Operations Control Team
NO-OP	no-operation
NOPE	Network Operations Project Engineer
NSC	Network Support Controller
NSR	near-simultaneous ranging
OCI	operator control input
ODA	Occultation Data Assembly
OLR	Open-Loop Receiver Assembly
OPNAV	optical navigation
ORT	Operational Readiness Test
OVT	Operational Verification Test
PCT	polynomial coefficient tape
PDT	Performance Demonstration Test
PESCAL	periodic engineering and science calibration
PET	probe ephemeris tape
PM	propulsion module
PMI	propulsion module ignition
PNV	Pioneer Venus
POCA	Programmed Oscillator Control Assembly

POR	power on reset
PPS	photopolarimeter
PPM	Precision Power Monitor
PRA	Planetary Ranging Assembly
PTP	pretrack preparation
PTT	project tracking tape
R&D	research and development
RF	radio frequency
RFI	radio frequency interference
RFS	radio frequency subsystem
RFSTLC	radio frequency subsystem tracking loop capacitor
RFSTLCO	radio frequency subsystem tracking loop capacitor offset
RS	Radio Science
RSS	Radio Science System (DSN)
RTC	Real-Time Telemetry Combiner
RTCS	real-time computer system
RTLT	round-trip light time
RTM	Real-Time Monitor
SAA	S-Band Acquisition Aid Antenna
SAMPLER	Science and Mission Plans Leaving Earth Region
S/C	spacecraft
SCA	Simulation Conversion Assembly
SCM	S-Band Cassegrain Monopulse (feed cone)
SDA	Subcarrier Demodulator Assembly
SEP	sun-earth-probe
SNR	signal-to-noise ratio

SNT	system noise temperature
SOE	sequence of events
SOPM	standard orbital parameter message
SPE	static phase error
SPT	System Performance Test
SRC	Subreflector Controller
SRM	solid (fueled) rocket motor
SSA	Symbol Synchronizer Assembly
SSI	Spectral Signal Indicator
STDN	Spaceflight Tracking and Data Network (GSFC)
TCM	trajectory correction maneuver
TCP	DSS Telemetry and Command Processor
TEL-IV	Telemetry at Cape Caneveral
TFL	time from launch
TLM	Telemetry System (DSN)
TODR	Temporary Original Data Record
TPA	Telemetry Processor Assembly
TSAC	Tracking System Analytical Calibration
TSF	track synthesis frequency
TTS	Test and Telemetry System
TWNC	two-way, noncoherent
USO	ultrastable oscillator
UVS	ultraviolet spectrometer
VCO	voltage-controlled oscillator
VGR	Voyager
VLBI	Very Long Baseline Interferometry System

VUIM	Voyager Interstellar Mission
WBDL	Wideband data line
XA	best-lock frequency (mathematical symbol)
XRO 2	X-Band Receive-Only (feed cone)

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