Voyager Support

R. Morris
DSN Operations Section

This is a first in a series of Deep Space Network reports on Tracking and Data Acquisition support for Project Voyager. This report covers the Network's pre-launch preparations and flight support through 31 December 1977.

I. Introduction

This is the first in a series of articles which will cover Deep Space Network operational support for Project Voyager. The purpose is to summarize tracking and data acquisition activities and the Network's performance in meeting commitments throughout the mission. Significant new capabilities were implemented for Voyager as part of the DSN Mark III 1977 Data Subsystem Implementation Project (MDS).[1] Consequently, network pre-launch test and training activities were extensive as described herein. Also, since this is the initial article, a brief mission–spacecraft description is provided for reference. Additional information on the mission is provided in Ref. 1.

II. General Mission Description

The objectives of the Voyager Project are to conduct exploratory investigations of the Jupiter and Saturn planetary systems, and the interplanetary medium between Earth and Saturn. This will be accomplished by two spacecrafts launched in 1977 on flyby trajectories that will employ Jupiter's gravitational assist to reach Saturn. Although not a formal objective, the Voyager mission design will not preclude one spacecraft from using a Saturn gravity assist to go on to a Uranus flyby.

A. Mission Design

The primary science objectives are to conduct comparative studies of the planetary systems of Jupiter and Saturn, including their environment, atmosphere, surface, and body characteristics. Also, objectives include the investigation of one or more satellites of each planet, the nature of Saturn's rings, and the interplanetary and interstellar media throughout the cruise phase of the mission.

Science instruments which have been selected for the Voyager mission are as follows: imaging television cameras; infrared interferometer, spectrometer, and radiometer; ultraviolet spectrometer, plasma wave analyzer, magnetometers, low-energy charged particle detectors, cosmic ray detectors, plasma detector, planetary radio astronomy receivers, photopolarimeter, and the spacecraft radio frequency communications link for celestial mechanics and radio science investigations.

The interplanetary cruise activities will gather data on the fields and particles environments of the Solar System as the

[1]The MDS Project has been described in numerous, previous Progress Report Articles.

mission modules move away from the sun. In addition, the pointing and stabilization capability of the mission modules will allow detailed observations of targets of opportunity that include comets, asteroids, stars, etc., that have not been possible on previous outer planet missions.

The second launched mission module (Voyager 1) will arrive first at Jupiter with closest approach on March 5, 1979, at about 5 Jupiter radii. The encounter geometry is illustrated in Figures 1 and 2. The second arriving mission module (Voyager 2) will have closest approach at Jupiter on July 9, 1979, at about 10 Jupiter radii. The encounter geometry is illustrated in Figures 1 and 3. Although the critical period for each encounter is measured in terms of a few days, the total encounter period of each mission module is approximately four months long. Planetary remote observations will be taken during this period and will provide many repeated cycles of total planetary mapping in the visual, ultraviolet and infrared wavelengths. At the same time, the fields and particles experiments will increase their activity to investigate the total planet-satellite environment. The first mission module will arrive at Saturn in late 1980, with the second arriving some nine months later as illustrated in Figures 4 and 5, respectively. Again, multiple satellite encounters are planned. The first mission module will also be targeted to occult the Rings of Saturn.

If the first mission module achieves its scientific objectives for the Saturn system, and if the second arriving mission module is operating satisfactorily, a decision could be made in early 1981 to target the second mission module for a Saturn aim point permitting an encounter with Uranus in 1986. Otherwise, the second mission module would be targeted to optimize Saturn-related science, including a close flyby of Titan prior to Saturn encounter. In either case, planetary observations of the Saturn system would last for about four months for each mission module.

By designing the mission modules to assure nominal operation out to Saturn, they are quite likely to continue to operate well beyond encounter with that planet. Following the Saturn flyby, both mission modules escape the Solar System with a heliocentric velocity of approximately 3 AU per year. Since departure is in the general direction of the Solar Apex, the spacecraft may return data (as a part of an extended mission) from the boundary between the solar wind and the interstellar medium. If an Uranus option is exercised for the second arriving mission module at Saturn, observations of the Uranus system would occur in 1986 over a time period from about three months before to one month after Uranus encounter. General design of the Uranus encounter phase observations would be similar to that at Jupiter and Saturn, except for the reduced data rates from a distance of 20 AU.

B. Earth-To-Jupiter Mission Phases

While Voyager flies on toward Jupiter, work continues on Earth for the planetary and satellite encounters to come. Figure 6 shows the planned Earth-to-Jupiter phases for both missions; dates and times given are for Voyager 1, launched September 5, 1977.

The early cruise phase lasted from post-launch to about 95 days into the flight. One trajectory correction maneuver (TCM) and a "clean-up" TCM were executed during the early cruise phase.

The cruise phase officially began when the high-gain antenna was turned toward Earth to remain in that position for most of the mission. The antenna must point toward Earth for communications. During the long cruise phase, nearly a year, one TCM is planned. In December 1978, during the last three days of the cruise phase, the near encounter test (NET) will be performed. The NET will be an actual performance of the activities scheduled for the period of closest approach to Jupiter.

Eighty days and approximately 80 million kilometers (50 million miles) from the Giant Planet, the Jupiter observatory phase will begin, about January 5, 1979. Following a quiet period over the holidays, periodic imaging with the narrow-angle camera will begin later in January, 1979. A third TCM is planned during this period. In early February 1979, a four-day movie sequence will record 10 revolutions of the planet, photographing the entire disk.

Following the movie phase will be the far encounter phases, as the spacecraft zeroes in on the planet, closing to 30 million kilometers (18.6 million miles) at 30 days out. The far encounter phases, from early February to early March, 1979, will provide unique observation opportunities for the four largest satellites – Lo, Europa, Ganymede and Callisto – and a crossing of the bow shock of the Jovian magnetosphere, of great interest to all of the fields and particles instruments. One TCM is planned during the far encounter phase.

For Voyager 1, near encounter will be a 39-hour period packed with close-range measurements by the spacecraft's 11 science experiments. On the outbound leg, five Jovian satellites – Amalthea, Io, Europa, Ganymede, and Callisto – will also receive close-range scrutiny by the various science instruments. Passing 280,000 kilometers (174,000 miles) from the visible surface of Jupiter, Voyager 1 will then whip around the backside of the planet, passing out of view of the Earth for a brief two hours.

The post encounter phases, from the end of near encounter to about 35 days later, will continue observations as the planet is left behind. Using the gravity of Jupiter to slingshot it on its way, Voyager 1 will flash onward toward the ringed planet Saturn, about 800 million kilometers (500 million miles) and 19 months distant. Voyager 1 will study Saturn from August through December 1980. Voyager 2 follows Voyager 1 through the same phases described except that a longer cruise to Jupiter and Saturn is involved for near-encounters on 9 July 79 and 27 Aug 1981 respectively.

III. Spacecraft Description

The Voyager Spacecraft embodies the Mission Module (MM) and the Propulsion Module (PM). The PM provides the final injection velocity on the desired flight path. The MM electronic and inertial reference components are used for PM control. The PM was separated from the MM after injection into the planetary transfer trajectory. The Mission Module is a three-axis stabilized craft based on previous Mariner and Viking Orbiter designs and experience, with modifications to satisfy the specific Voyager Mission requirements on long-range communications, precision navigation, solar-independent power, and science instrumentation support.

The current spacecraft configuration is shown in Figure 7. The 3.66 meter (12 feet) diameter high gain antenna (HGA) provides S- and X-band communication. The X-band antenna dichroic subreflector structure serves as a mounting platform for the low gain antenna (LGA) and the HGA S-Band focal point feed. The bi-stable Sun sensors in conjunction with the Canopus tracker (mounted on the electronic compartment) provides the celestial reference for three-axis stabilized attitude control of the Mission Module. Hydrazine thrusters mounted on the MM provide both reaction-control torque for MM stabilization and thrust for Trajectory Correction Maneuvers (TCMs).

IV. DSN Operational Test and Training

For pre-launch, launch, and early-mission support, the DSN committed readiness of Network Stations as follows: (1) CTA-21 for spacecraft-network compatibility tests and DSN development, (2) STDN MIL-71 for spacecraft-network compatibility verifications and near-earth launch support, (3) one 26 meter subnet of three stations: DSS 12 (Goldstone CA), DSS 44 (Australia), and DSS 62 (Spain) for cruise support, and (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 compabilities required were provided through the DSN Mark III '77 Data Subsystem (MDS) Implementation Project per the schedule shown in Fig. 8. Mission-dependent network tests 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 were two-fold. 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) were started immediately after all SPT's were completed. This being the first Goldstone Complex 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 was to:

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

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

(3) To 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 (OVT's). Approximately 30 percent of the OVT's performed at station 12 produced more problems than training benefit. (A total of 10 OVT's were run with DSS-12.) It was not until half of these tests were completed before results of the training could be seen. This was not altogether unexpected, and the problems experienced with station 12 led to identifying, documenting, and eventual corrections of hardware configurations, software and procedures. Further DSN tests with CTA-21 and MIL-71 also contributed to this effort.

By the time DSS-62 DSN testing (OVT's) were begun new CMD, TLM, and CMF software versions (Ver. A) were at the station. Test results began to improve. All OVT's 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 OVT's at DSS-44 was unsuccessful, and it 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 has been used for initial acquisition). Special Initial Acquisition OVT's were run to familiarize station personnel with Initial Acquisition procedures. These tests went very smoothly. Several tests using a GEOS satellite (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 live with the limited test and training risks.

The first test with DSS-14 was on 27 June 77. The test failed due to station air conditioning problems and a NDPA software failure. Approximately one-half of the DSS-14 OVT's experienced major difficulties; mostly hardware in nature. Problems with DSS-14 continued into the first 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) OVT's were conducted with DSS-14 which provided additional training. (SAMPLER was cancelled by project before launch.)

In the last three weeks before launch of Voyager 2 several MOS tests were conducted, with the spacecraft (at Cape Canaveral) providing the TLM 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 14/15 August, 1977. Stations participating in this test were MIL-71, DSS-11, -12, -14. Both DSS-12 and -14 experienced some equipment and operations anomalies, however it was felt that they could be corrected before launch.

Since DSS-44 had not been active on Voyager in about two months, an OVT was performed on 17 August to insure personnel proficiency. The station's performance was excellent.

Station Configuration Verification Tests (CVT) were conducted with MIL-71, DSS-11, -12, -14, -44, and -62 on 17, 18, 19 August 1977. With these CVT's the stations were placed under configuration control for Voyager 2 launch. (Table 1 gives a summary of all prelaunch tests conducted.)

*Mission Operational System.

Voyager 2 launch occurred on 20 August 1977 at the launch window opening.

Between Voyager 2 launch and Voyager 1 launch (5 September) the recertification of DSS-14 was ensured by performing a CVT on 4 September. DSS's-12, 44, 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 (42/43) was taken down in July 1977 for the Mark III Data system conversion. The 42/43 combined system test was conducted on 24 September 1977, signaling the end of System Performance Testing (SPT's) and the start of the 2 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 is a minor change to the basic 64/26m MDS configuration we did not fully understand the impact to operations or what to expect in the way of interaction.

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 Operational Verification Testing (16 hours per day) completing the first week. Viking was selected because it was a project the operational personnel would be 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 OVT's per crew were conducted during the month of October. All but one OVT was very successful. Station operational personnel were highly motivated and their performance for the most part was excellent. On the 31st of October 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 Oct. through December 1977. DSN Operational testing started in early January, 1978. Again, a minimum of two OVT's were conducted with each operational crew. Simulation Conversion Assembly (SCA) and comm 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.

Deep Space Station 11, the last of the network to be converted, was taken down on schedule (mid January) and is not covered by this report.

V. Spacecraft Operations

A. Prelaunch Activities

Three spacecraft were built for the Voyager Mission, one (VGR77-1) was designated the Proof Test Model (PTM) and subjected to extensive testing in simulated deep space conditions to test the spacecraft design, construction, and durability. VGR77-2 and VGR77-3 were designated flight spacecraft and subjected to less arduous testing to save them for flight conditions.

Failures in the Attitude and Articulation Control Subsystem (AACS) and Flight Data Subsystem (FDS) on the VGR 77-2 spacecraft, planned to be launched first on August 20, 1977, resulted in a decision to interchange the two flight spacecraft. The VGR77-3 spacecraft was redesignated Voyager 2 and launched first.

The decision to switch the flight spacecraft necessitated switching of the Radioisotope Thermoelectric Generators (RTG's) as well. Since the first launch trajectory includes the option to extend the mission to Uranus, a distance of 19 Astronomical Units (AUs) from the sun, the higher power output RTG's previously installed on VGR77-2 were removed and reinstalled on VGR77-3.

B. Voyager 2 Operations

Voyager 2, aboard a Titan IIIE/centaur launch vehicle, lifted off launch complex 41, Air Force Eastern Test Range (AFETR), Cape Canaveral, Florida at 14:29:45 GMT, August 20, 1977. The time was less than 5 minutes into the launch window on the first day of a 30 day launch period. The countdown progressed smoothly except for a brief unscheduled hold at launch minus five minutes to determine the open/closed status of a launch vehicle valve. Minutes after launch, however, several problems were noted.

These problems included a suspected gyro failure, incomplete data transmission, and uncertainty as to the deployment of the science platform boom. The gyro failure and data transmission problems cleared. The boom supporting the science platform was to be released and deployed about 53 minutes into the flight, but initial data gave no confirmation that the boom was extended and locked. (When the boom is within 0.05 degrees of normal deployment, a microswitch on the folding boom opens.) Confirmation of the microswitch position was not received.

On August 26 the spacecraft was programmed to execute a pitch turn and simultaneously jettison the dust cover on the infrared interferometer spectrometer (IDIS) in hopes that enough jolt would be provided to open the boom hinge and slow the locking pin to drop into position. However, the sequence was aborted by the spacecraft before the events could take place. (The spacecraft is programmed to think such a maneuver is an emergency and will safe itself, aborting the maneuver.) It is still not certain that the science boom aboard Voyager 2 is 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 is stiff enough to prevent wobbling when the scan platform, perched at its tip, is 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 is now in stable condition.

By September 1, Voyager 2 was 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 September 23, Voyager 2 experienced a failure in the Flight Data Subsystem (FDS) circuitry which resulted in the loss of 15 engineering measurements sent to earth. An effort to reset the FDS tree switch was performed on October 10th, but was unsuccessful. The problem is now considered a permanent hardware failure and "work around" alternatives are being used.

This failure affects 15 separate engineering measurements, an internal FDS measurement and four redundant measurements. Voyager 2's first trajectory correction maneuver (TCM) was performed on October 11, achieving the desired correction to within one percent.

In anticipation of experiencing a similar thruster plume impingement to that observed on Voyager 1's first TCM (later in this article), 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. Voyager 2's closest approach to Ganymede is now planned for about 60,000 kilometers (37,000 miles) rather than 55,000 kilometers (34,000 miles) on July 9, 1979.

On October 31, 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 was contributing to the frequent attitude control thruster firings to steady the ship 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 returned to as celestial reference.

Voyager 2 was put through some sequence verification tests December 5, 7, and 8, performing flawlessly. Then on December 27, 28 the spacecraft performed a cruise science maneuver. This maneuver allows calibration of several instruments by turning the spacecraft to look at the entire sky. The scan platform instruments are able to map the sky as the spacecraft rolls, and the ultraviolet spectrometer and photopolarimeter make their observations against the total sky background. The magnetometer and plasma instrument also obtain calibration data.

The cruise science maneuver consists 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 this 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.

A degradation of the S-band radio solid-state amplifier in the high power mode has been noted. The amplifier has been switched to the lower power mode and is being monitored. The radio system has built-in redundancy, using both solid state amplifier and a traveling wave tube amplifier.

On 2 February 1978, at 1104 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 1407 GMT and DSS-63 was released by the Viking project to answer 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 stations' data was marginal due to 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 6 hours, by which time the flight team could determine if the sensor was still on Canopus. But the spacecraft flight team had begun their unmanned period with DSS-44 end of track. The timer ran down and the computer "safed" the spacecraft by switching to low gain antenna. This dropped the downlink by 29dB (below TLM threshold). The spacecraft team was called in and, after studying the problem, commanded the spacecraft back to HGA, acquired Canopus and reset the Canopus sensor cone angle to center Canopus in the tracker. After a computer readout was performed, confirming normal configuration, the spacecraft emergency was terminated at 2125 GMT, same day.

Voyager 2 continues in cruise mode.

C. Voyager 1

Due to the problems experienced with Voyager 2's science boom it was decided to de-encapsulate Voyager 1 (VGR77-2) on 20 August for inspection of the science boom, and installation of stiffer coil springs to assure proper boom deployment and locking.

Engineers had conducted several tests on the mechanical configuration of the VGR77-1 (PTM) science boom, including torque tests on the microswitch and stiffness test of the boom.

The Centaur shroud was placed over the spacecraft on August 29, and post-encapsulation electrical test was conducted in preparation for mating to the launch vehicle. Movement to the launch pad occurred on 31 August 1977.

Voyager 1, aboard a Titan III E/Centaur launch vehicle, lifted off launch complex 41 at the Air Force Eastern Test Range (AFETR), at 12:56:01 GMT, September 5, 1977, sixteen days after its twin. The launch countdown went smoothly with no unscheduled holds.

None of the attitude control problems encountered during the launch of Voyager 2 were experienced. A switch to the secondary thruster system was noted during the magnetometer boom deployment; a reset to initial conditions was commanded about 12 hours after launch.

Voyager 1, due to the alignment of the planets at the time of launch, will fly a faster trajectory relative to the Sun and will arrive at Jupiter 4 months ahead of Voyager 2. The Jupiter observation phase will begin the 1st week in January, 1979. The spacecraft will travel a total of 998 million kilometers (620 million miles) to Jupiter, its first destination.

Voyager 1 completed its first trajectory correction maneuver (TCM) in two parts on September 11 and 13. An analysis of the TCM data indicated a 20 percent under-velocity 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 at the Goldstone complex near Barstow, California.

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

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

A recorded Earth-Moon video and optical navigation data sequence was conducted on September 18, in which dramatic pictures of the Earth and moon were recorded from 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 October 29, 1977. The maneuver was successful, with pointing accuracies and undervelocity resulting during the first trajectory maneuver on September 11 and 13 being accounted for in the sequence.

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

Voyager 1, on December 15, 1977, earned its title when it took over the lead from Voyager 2 and is now farther away from Earth and Sun.

Presently Voyager 1 is in Earth-Jupiter cruise with all subsystems and experiments in good working condition.

VI. Tracking and Data Acquisition

From the moment of launch, the Voyager spacecrafts have been under alternating surveillance by a world-wide tracking and data system which includes elements of the NASA/JPL Deep Space Network, the Air Force Eastern Test Range (AFETR), and the NASA Spaceflight Tracking and Data Network (STDN).

A. Near-Earth Launch Support

The Near-Earth coverage, from launch through the propulsion module burn which boosted the spacecrafts into the Jupiter-bound trajectories, was accomplished by the near-Earth facilities. These consist of the AFETR stations downrange elements of the STDN, ARIA (Advanced Range Instrumented Aircraft), and a tracking communications ship at sea, the USNS Vanguard.

For the first launch, Voyager 2, coverage, data acquisition, and real-time acquisition were excellent. Resources proved to be in the right place at the right time to preclude unplanned data outages. The near-Earth non-real-time data return plan was executed resulting in practically all near-Earth data available to project.

The Voyager 1 launch support on 5 September went very smoothly. The near-Earth facilities again turned in an excellent performance retrieving the data in a timely manner to the Voyager project.

B. Deep Space Network (DSN) Support

Tracking and data acquisition communications with the Voyager spacecrafts from injection into the Jupiter trajectories, about one hour after launch, until the end of the mission is conducted by the Deep Space Network (DSN).

Initial acquisition of both Voyager spacecraft was conducted by DSS-12, with backup being provided by DSS-11 and DSS-14. Both initial acquisitions went according to plans.

On the first launch (Voyager 2), DSS-14 was prime for the 7.2 kb/s telemetry data, which occurred shortly after initial acquisition. Due to an operations procedural error in frequency predictions sent to the station, DSS-14 was 25 minutes late acquiring the spacecraft signal. There would have been a loss of data if MILA/MIL-71 had not acquired the 7.2 kb/s data on time and made it available to the Voyager Project.

MILA/MIL-71 again came to the rescue, when at 1638Z (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 bps. MILA/MIL-71 immediately detected this change, locked up on the data and alerted the network. All stations responded quickly and data outage was negligible.

Upon launch of Voyager 1, DSS-11 acquired the spacecraft about 2 minutes before DSS-14 and DSS-12. Since DSS-11's (not a MDS station) data was record only, the project chose to process DSS-14's telemetry as prime from Goldstone. Telemetry from DSS-14 continued without problems until LOS. DSS-12 experienced some difficulty reacquiring the spacecraft downlink after going two-way. The difficulty was caused by a 12 Hz filter failure.

Both spacecraft are presently 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 have been anything but routine. Spacecraft anomalies have dictated real time commands, special maneuvers calibration sequences and tests not originally planned for the cruise phase. The DSN has responded in real time to satisfy all project requirements where resources have allowed. Additionally, special tests and procedures to support these tests and calibration sequences were developed and implemented as required.

C. Weilheim Tracking Support

The Voyager and Helios Projects decided to take advantage of an alignment of their respective spacecraft and the Earth which during the period between Oct. 15 and late Dec., 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 spacecrafts. In order for the Weilheim station to track the Voyager spacecrafts, the DSN provided tracking predicts (state vectors) and a Communications decoder for interfacing with the NASCOMM 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 during the week of Oct. 17.

Weilheim continued to gather the Voyager spacecraft data until 31 December 1977 when support was terminated; the period of radial alignment having passed. A spiral alignment of the two spacecraft will occur in April 1978 and Weilheim is again expected to track Voyager.

VII. DSN Performance

A. Tracking

The Voyager 2 launch and near-Earth phases were marked by spacecraft and data acquisition anomalies resulting in a less than smooth beginning for the Voyager 2 mission. DSN tracking procedures, conservatively designed to encompass launch contingencies, contributed to the successful completion of this phase of the Voyager mission. The launch of the Voyager 1 spacecraft proceeded very smoothly, with none of the problems of predict generation, station reception or spacecraft anomalies, as experienced with the earlier launch.

The unique geometry (zero declination) which will exist at Saturn encounter for both Voyager spacecraft will make impossible the determination of spacecraft declination by Doppler fitting techniques. An alternate method of determining declination requires that range data be taken nearly simultaneously from stations at widely separated latitudes and triangulating to solve for the declination angle. This method, Near Simultaneous Ranging (NSP), requires very accurate range measurements and delay calibration data be furnished to the spacecraft navigator and the radio scientists. The acquisition of NSR data also requires that the up and down link signals remain phase coherent during station transfers. Since this is not possible using the standard DSN transfer technique, a new transfer technique which enables two stations to maintain the necessary phase coherence during transfers was devised and implemented during NSR passes, occurring approximately every 14 days.

B. Command

Due to spacecraft anomalies and additional instrument calibration requirements, more spacecraft commands have been sent to date than originally planned prior to launch. A total of 11,255 commands to Voyager 1 and 12,977 commands to Voyager 2 were transmitted 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.

Several command anomalies have occurred since launch. Two of the most significant failures were software related and were eventually corrected with a new Command Processor Assembly (CPA) software version (DMC-5084-OP-C). These were 1) loss of response from a stations CPA, because the CPA Temporary Operational Data Record (TODR) would write past its partitioned space, destroying a portion of the CPA program, and 2) random inability to access either CPA, caused by a software anomaly in the CPA timing.

C. Telemetry

All critical mission activities such as TCM's, celestial reference changes, cruise science maneuvers, special calibrations, spacecraft emergencies, etc. require accurate telemetry link predictions to guarantee any measure of success. The telecommunications links have been accurately predicted in most all instances by both the DSN and project spacecraft and telecomm 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 show that downlink AGC values for both spacecraft are near nominal while symbol Signal-to-Noise Ratios (SNR) are about +2dB. X-band performance for Voyager 2 is also within 0.5dB of predicts.

Intermediate Data Records (IDR's) have been provided on each pass. The DSN commitment of at least 96 percent has been exceeded, usually averaging approximately 99.6 percent of all data received.

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Tracking: G. Spradlin, J. Wackley, L. G. Chandler, K. Weld.

Command: D. Lopez, W. Tucker

Reference

1. Voyager mission status bulletins 1 through 14, published by the Jet Propulsion Laboratory (JPL internal documents).

Table 1. Summary of prelaunch VGR test activities (15 Nov. 76 through 19 Aug. 77)

Test	CTA-21	MIL-71	*DSS-11	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	7	2	0	5	1	1	1
INIT. ACQ.	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	0	4	0	4	7	1	2
ORT	0	2	2	2	2	1	1

*Non MDS Station

DFT = Data flow test
OVT = Operational verification test
PDT = Performance demonstration test
CVT = Configuration verification test
MEIVT = MCCC external interface verification test
DEIVT = DSN external interface verification test
GDS = Ground data system test
MOS = Mission operation systems test
ORT = Operational readiness test

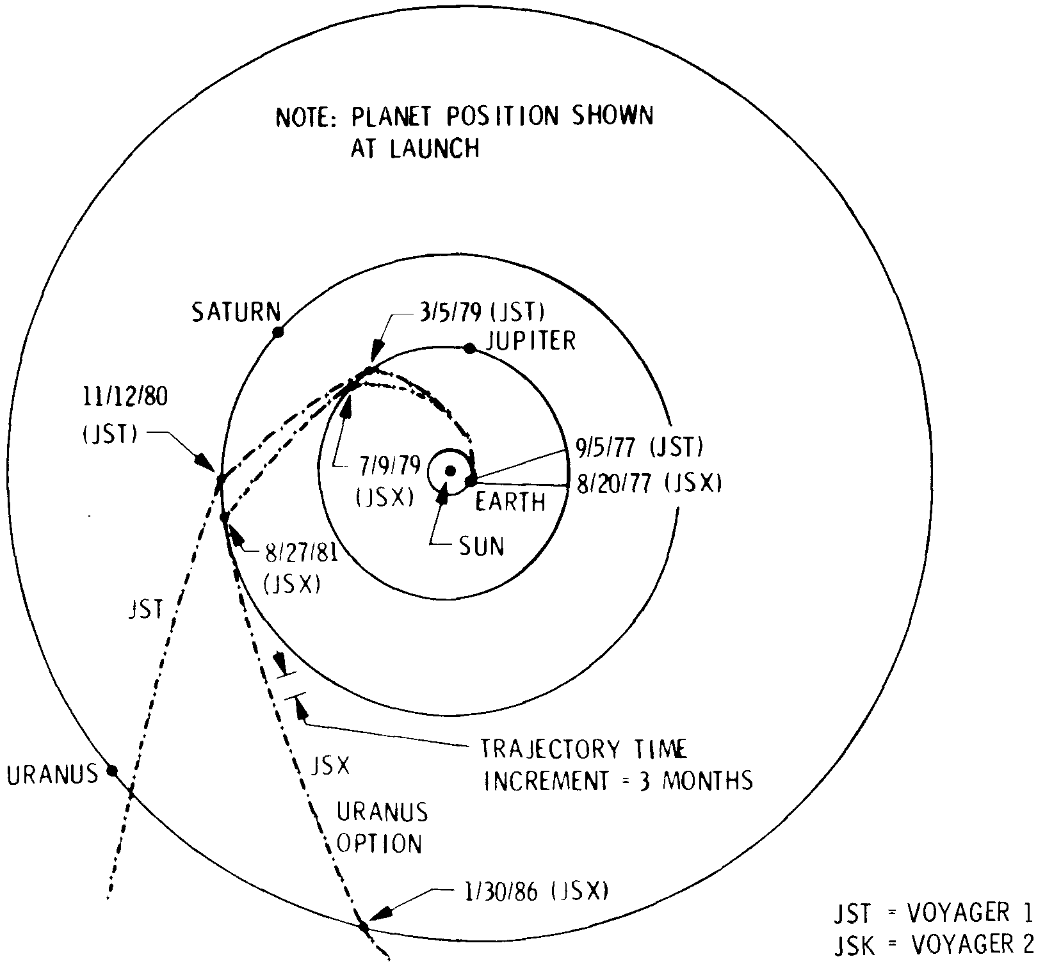

Fig. 1. Trajectories JST and JSX

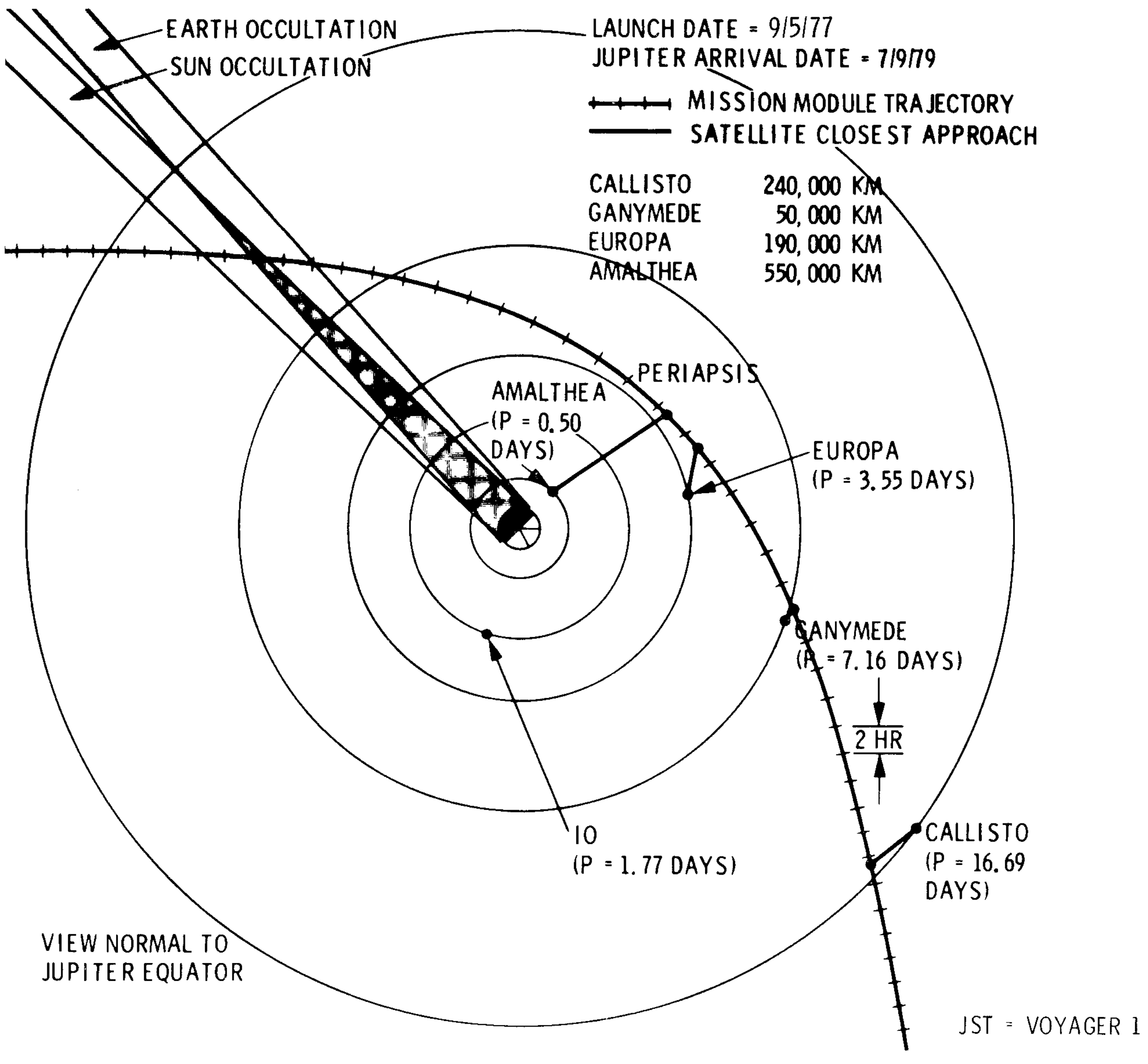

Fig. 2. JST Jupiter encounter at $4.9R_J$

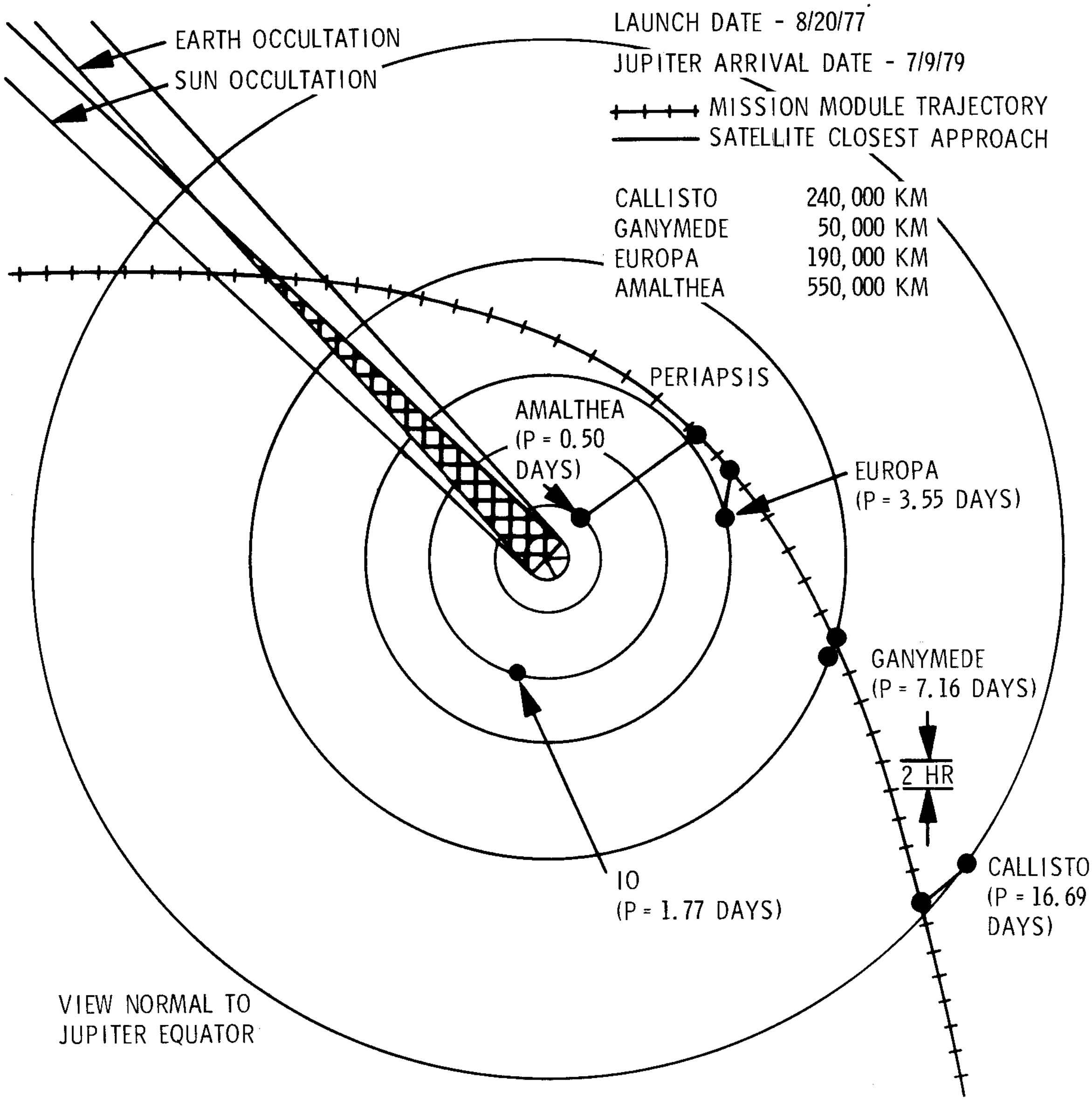

Fig. 3. Voyager 2 Jupiter encounter at $10R_J$

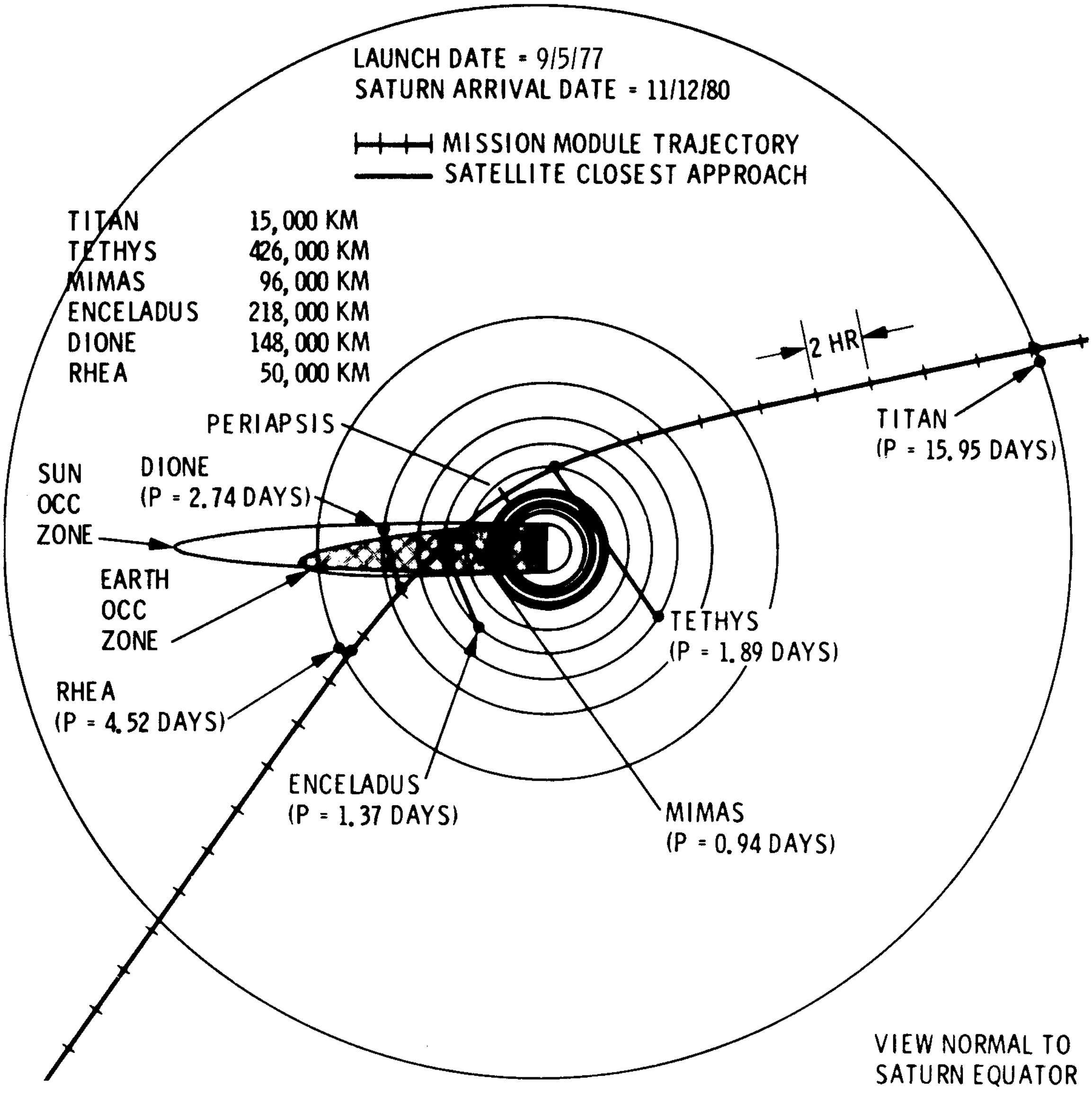

Fig. 4. Voyager 1 Saturn encounter at $3.3R_S$

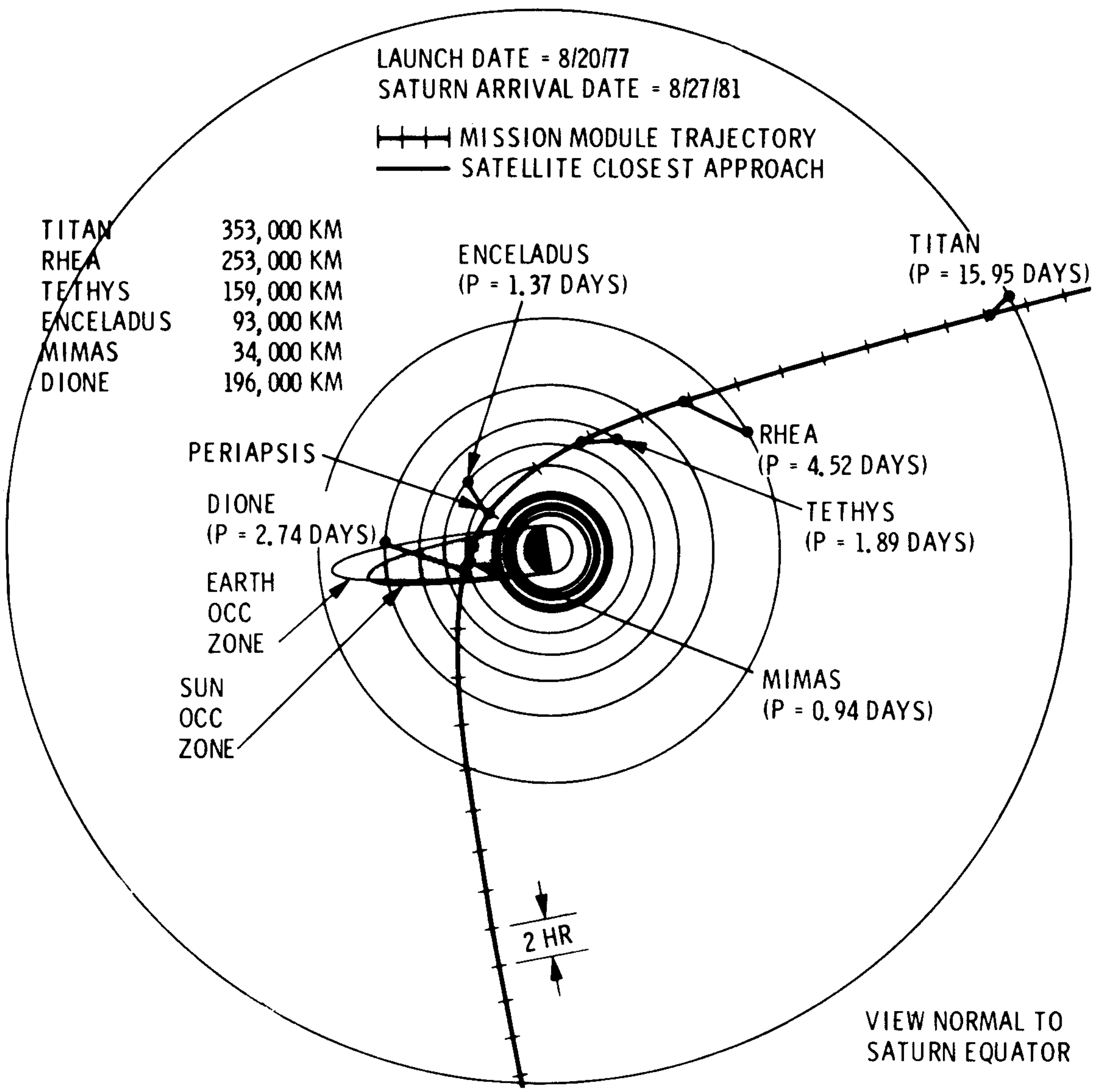

Fig. 5. Voyager Saturn encounter at 2.7R_S

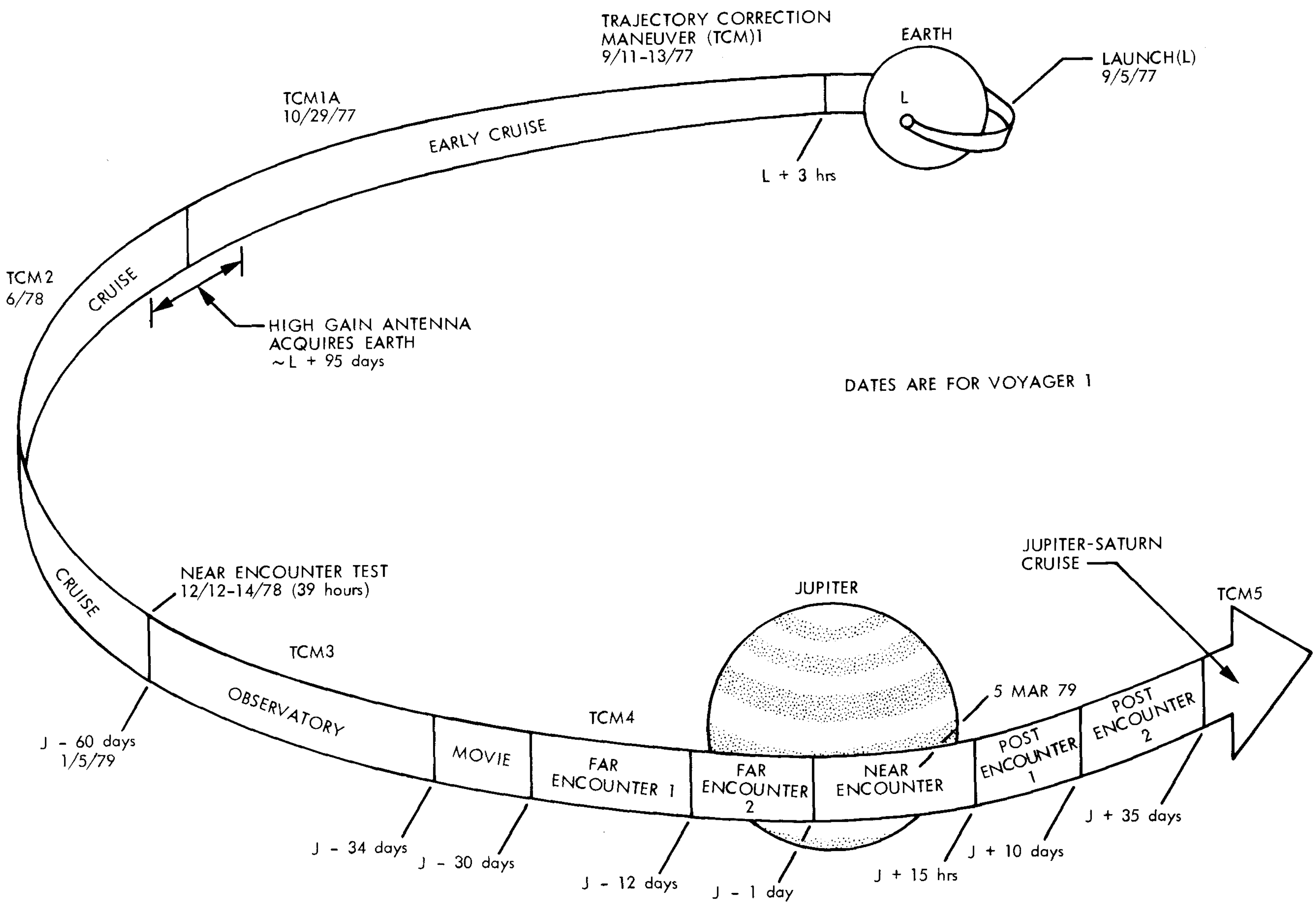

Fig. 6. Voyager 1 mission phases, Earth to Jupiter

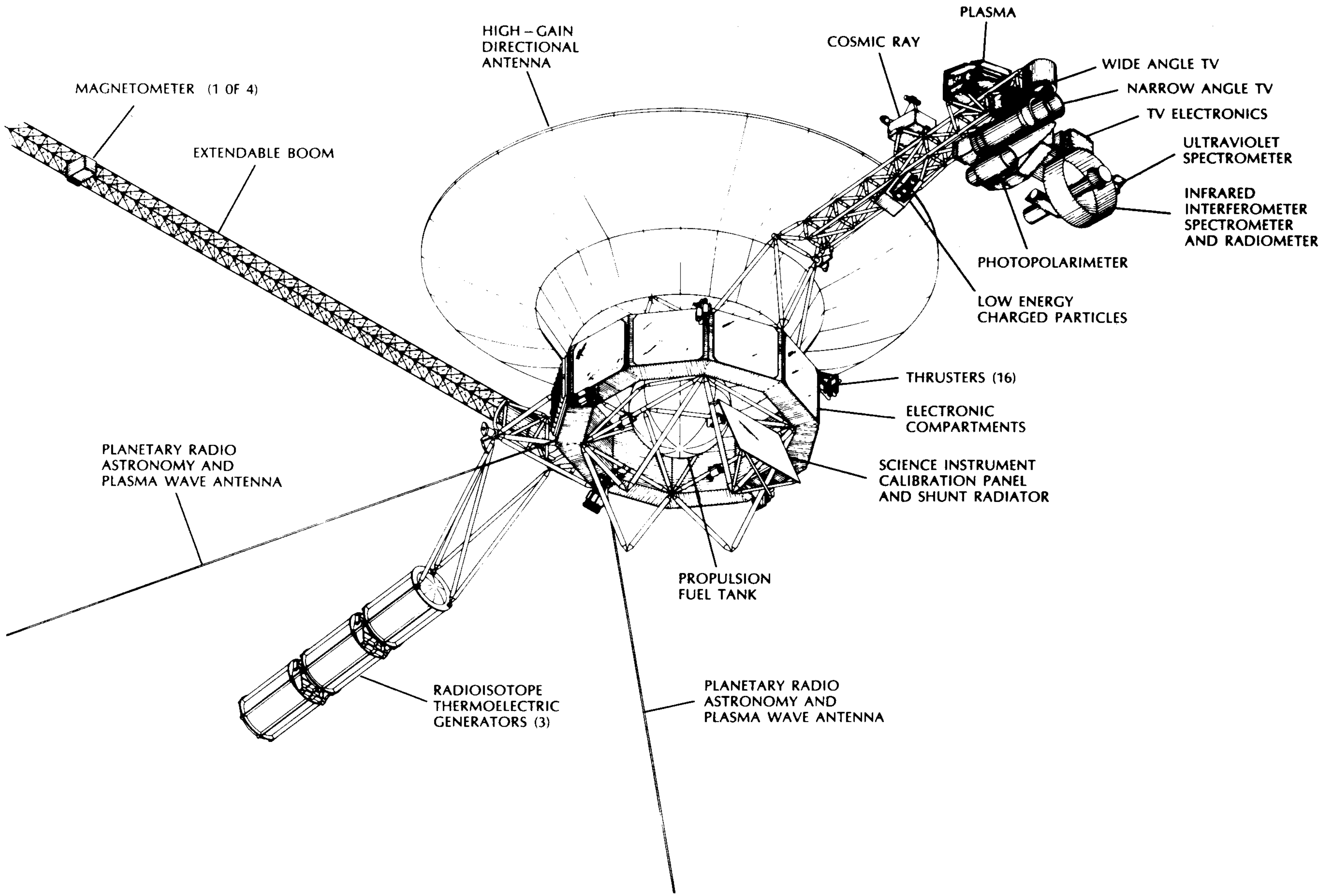

Fig. 7. Voyager spacecraft configuration

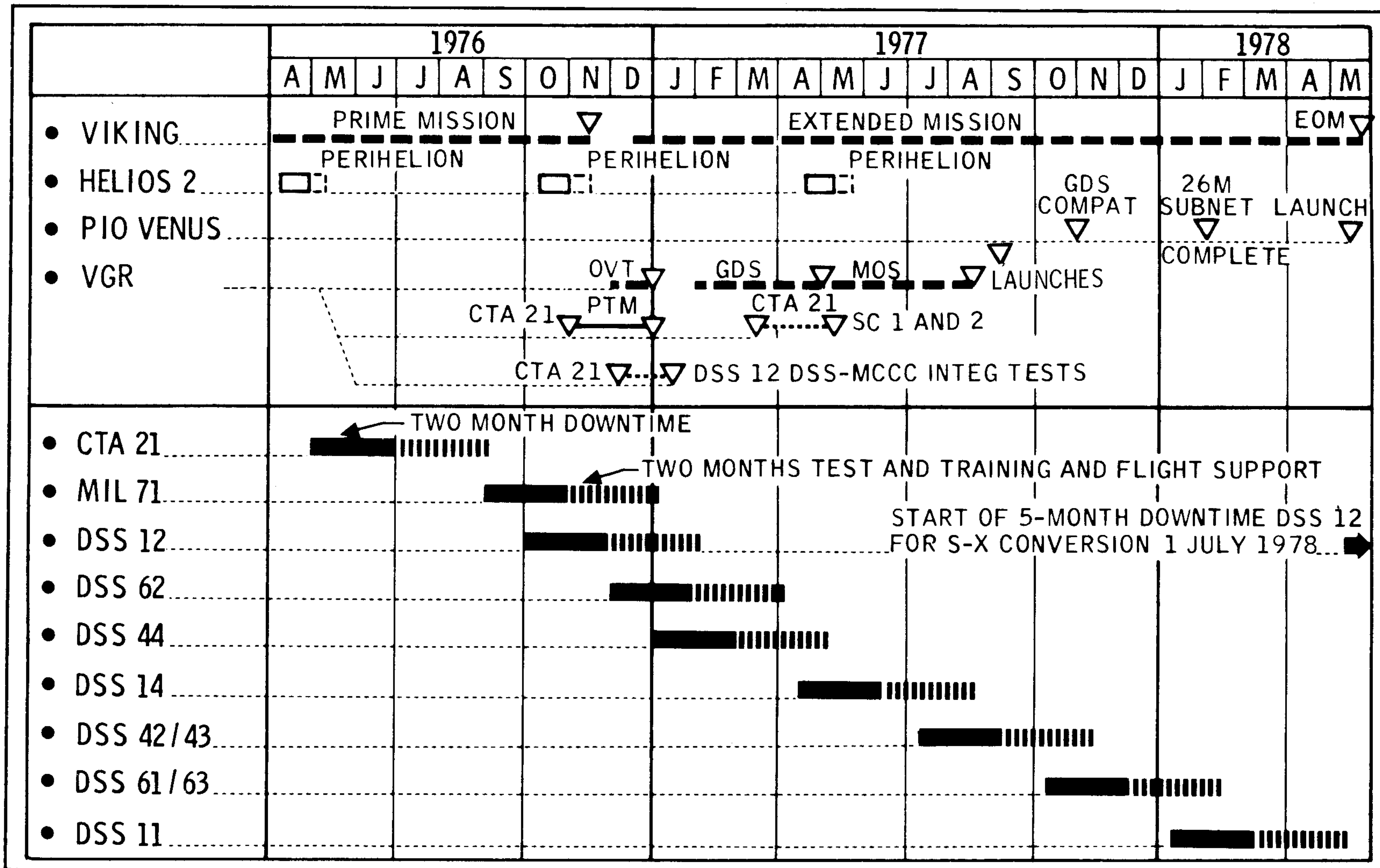

Fig. 8. Mark III-DSN Data Subsystems Implementation Project schedule