NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-584

Volume II

Tracking and Data System Support for the Pioneer Project

Pioneer 11 – Prelaunch Planning Through Second Trajectory Correction: to May 1, 1973

W. R. Barton

R. B. Miller

(NASA-CR-142698) TRACKING AND DATA SYSTEM SUPPORT FOR THE PIONEER PROJECT. VOLUME 2: PIONEER 11 PRELAUNCH PLANNING THROUGH SECOND TRAJECTORY CORRECTION, TO 1 MAY 1973 (Jet Propulsion Lab.) 142 p HC $5.75 CSCL 22C G3/17 N75-21335 Unclas 19427

JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

March 15, 1975

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-584

Volume II

Tracking and Data System Support for the Pioneer Project

Pioneer 11 – Prelaunch Planning Through Second Trajectory Correction: to May 1, 1973

W. R. Barton

R. B. Miller

JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

March 15, 1975

Prepared Under Contract No. NAS 7-100
National Aeronautics and Space Administration

PREFACE

The original design for this series of documents, which was described in the Preface to Volume I, has been changed.

This volume is one of a series of documents describing and evaluating support of the Pioneer 10 and 11 Jupiter Missions; Project management is at the Ames Research Center of the National Aeronautics and Space Administration. The work described in this volume was performed by the Tracking and Data Acquisition organizations of the Jet Propulsion Laboratory, under the direction of N. A. Renzetti, Tracking and Data System Manager for the Pioneer Project; the Air Force Eastern Test Range; the Spaceflight Tracking and Data Network; and the NASA Communications Network of the Goddard Space Flight Center.

Volume I covered the Tracking and Data System support for the Pioneer 10 Jupiter mission from 4 December 1969 to 1 April 1972. This period encompassed the prelaunch planning phase through the second trajectory correction maneuver plus one week. The second trajectory correction maneuver was performed March 24, 1972.

This document, Volume II, describes TDS support of the Pioneer 11 Mission through prelaunch planning, launch of the spacecraft, the second trajectory correction maneuver, and into the cruise phase. The second trajectory correction occurred April 26, 1973, and the reporting period ends on April 30, 1973. The next report on the Pioneer 11 Mission (Volume IV) will begin with May 1, 1973, and will include the Jupiter encounter events of December 1974.

Volume III will cover TDS flight support of Pioneer 10 from April 1, 1972 through the Jupiter flyby period (January 1974). Subsequent volumes will cover TDS flight support of extended missions of the Pioneer 10 and 11 spacecraft on a periodic basis.

ACKNOWLEDGMENT

Tabular data was extracted from DSN internal monthly reports published by the network operations organization under D. L. Gordon. The near-Earth support information was provided by R. M. Grace, TDS coordinator for the JPL/AFETR Near-Earth Phase. In addition, some material was abstracted from Ames Research Center reports.

CONTENTS

TABLES

FIGURES

ABSTRACT

This report describes the Tracking and Data System support of the planning, testing, launch, near-Earth, and deep space phases of the Pioneer 11 Jupiter Mission, which sent a Pioneer spacecraft into an encounter of Jupiter on a trajectory that might also allow guidance of the spacecraft to a flyby of Saturn. The support through the spacecraft's second trajectory correction is reported. During this period, scientific instruments aboard the spacecraft registered information relative to interplanetary particles and fields, and radio metric data generated by the network continued to improve our knowledge of the celestial mechanics of the solar system. Network performance and special support activities are covered in addition to details of network support activity.

I. INTRODUCTION

A. MISSION DESIGN AND OBJECTIVES

The Pioneer 11 Mission was designed primarily to conduct exploratory investigations of the interplanetary medium beyond the orbit of planet Mars, to ascertain the nature of the asteroid belt, and to probe the environmental and atmospheric characteristics of the planet Jupiter during the spacecraft flyby on December 5, 1974 (a year and a day after the Pioneer 10 spacecraft flyby). The Pioneer 11 spacecraft journey to Jupiter was 992×10^6 km. The trajectory and sequence of events up to Jupiter flyby were designed to be similar to those of Pioneer 10. However, Pioneer 11's trajectory profile was such that it would be possible to either duplicate the Pioneer 10 Jupiter encounter, or flyby the opposite side of the planet enabling an encounter of the planet Saturn in 1979. The final decision on the Pioneer 11 targeting at Jupiter was to be made after the Pioneer 10 Jupiter encounter.

The secondary objective of the National Aeronautics and Space Administration's (NASA's) Pioneer 11 Mission was to advance technology and operational capability for long-duration flights to the outer planets.

Launched April 6, 1973, Greenwich Mean Time (GMT), within a period of best opportunity for near Jupiter flyby (the opportunity occurs every 13 months), the Pioneer 11 spacecraft continued to be successfully supported at the end of the period covered by this document. On April 30, 1973, the spacecraft was 22.1×10^6 km from Earth.

Like Pioneer 10, Pioneer 11 carries "a message from Earth." This message, designed to indicate the locale, epoch, and nature of the builders to any advanced technological society that might intercept the spacecraft, is described in detail in Appendix A of Ref. 1. That Tracking and Data System (TDS) document covers the period of Pioneer 10 support from prelaunch planning through the second trajectory correction. Applicable to the Pioneer 11 Mission in many facets, the Pioneer 10 document is a reference for this report for background and description of the TDS role, support by the Deep Space Network (DSN) and its facilities and basic systems, scientific objectives and experiments, and the configurations of launch vehicle and spacecraft. Much of that material is not repeated in this document.

B. PIONEER PROJECT BACKGROUND

Initiated in 1958 as part of the U. S. participation in the International Geophysical Year, Pioneer Project evolved the following generations of missions:

(1) First Generation: Pioneers 1 through 5, 1958 to 1960 (approved March 27, 1958). These missions were lunar probes assigned to the NASA by Executive Order on October 1, 1958, the day that NASA became an independent agency. NASA delegated to the Air Force and the Army the authority to direct these projects. The Jet Propulsion Laboratory was responsible for designing and building Pioneers 3 and 4. Pioneer 5 was developed by the Space Technology Laboratory (STL), now TRW Systems Group, TRW, Inc. Pioneer 5, in closing out the first Pioneer generation, remained active in space more than 3 months and was not lost to Earth contact until it was 27.5 million km from Earth. This was a new record.

(2) Second Generation: Pioneers 6 through 9 and E, 1965 to 1969 (approved November 9, 1962); managed by the Ames Research Center (ARC) for NASA.

(3) Third Generation: Pioneer F (designated "10" after its launch in 1972) and Pioneer G ("11" after its launch in 1973). They were approved February 8, 1969 with ARC again managing for NASA.

The second and third generation Pioneers were specified by ARC and designed and built by TRW. Figure 1 is a DSN support schedule for Pioneer 6 through 11 spacecraft.

1. Second Generation Spacecraft

The second generation of spacecraft continued to furnish scientific and engineering data at the conclusion of the report period of this document. The assigned mission objectives and design life-time goals had been exceeded because of judicious redundancy in the design of the spacecraft and close monitoring of the spacecraft performance.

This longevity of the Pioneers 6 through 9 spacecraft extended the state-of-the-art for deep space mission planning, design, and operations, and enabled mission planners to realistically consider the extended probes of space and the planets. The primary objective of the Pioneer 6 through 9 Missions was to accumulate scientific data from deep space, and to provide a study of the magnetic field, spatial plasma, cosmic rays, high-energy particles, electron density, electric fields, and cosmic dust within a region of 0.75 to 1.20 AU from the Sun. Near-real time data reduction and analysis was a part of a Pioneer space weather report teletyped regularly to the U. S. Space Disturbance Forecast Center.

Various specific engineering mission objectives were accomplished through use of the Pioneer signal from Pioneers 6 through 9. The effect of charged particles on the accuracy of the tracking doppler data was investigated. Pioneer data contributed to network corrections of doppler orbit determination data. Very accurate station location information was obtained not only for the NASA Space Network but also for large antennas owned by other governments. These results were valuable in support of the Apollo trajectory effort.

All the second-generation spacecraft were launched from Cape Kennedy Space Flight Center in Florida. Launch dates, heliocentric orbits, and number of scientific instruments carried were:

Pioneer 6: Dec. 16, 1965, inward orbit, 6 instruments.
Pioneer 7: Aug. 17, 1966, outward orbit, 6 instruments.
Pioneer 8: Dec. 13, 1967, outward orbit, 7 instruments.
Pioneer 9: Nov. 8, 1968, inward orbit, 7 instruments.

Pioneers 8 and 9 launch vehicles also carried "piggyback" a Manned Space Flight Network (MSFN) Test and Training Satellite (TETR-2), which was separated in Earth orbit and used in command simulation for Apollo station training.

A Pioneer E spacecraft in the same generation launched on August 27, 1969, was destructed after 438 s of flight. A destruct signal was transmitted because of a loss of hydraulic pressure in the first stage.

2. Achievements

Achievements of the first- and second-generation Pioneer spacecraft are summarized in Table 1.

3. Pioneer 10

The first spacecraft of the third generation was successfully continuing its mission during the time period of this document.

C. PIONEER PROJECT MANAGEMENT

The NASA Headquarters Office of Space Sciences was responsible for the planetary programs. The Pioneer Program Manager headed all activities of the Pioneer Project. NASA's Ames Research Center (ARC), located at Moffett Field, Calif., was in charge of all management coordination and control aspects for the Pioneer missions. The Pioneer Project Office was headed by the Pioneer Project Manager who was supported by a Project staff. The staff assisted him in the areas of management control mission analysis, launch coordination, nuclear power, scientist coordination, contracts, magnetics, reliability, and quality assurance.

In addition, seven government-sponsored organizations supported the Pioneer 11 Mission with specific services. The Space Nuclear Systems Division of the Atomic Energy Commission controlled the development and production of the radioisotope thermoelectric generators (RTGs). Teledyne Isotopes was the prime contractor for these generators. The Experiment System, Spacecraft System, and Mission Operations System were supported by individual teams of the Ames Research Center. The spacecraft contractor was TRW Systems Group, TRW, Inc. The Bendix Field Engineering Corporation provided the electronic data processing support for the Mission Operations System. The Jet Propulsion Laboratory was the tracking and data acquisition center of the Pioneer missions and planned, managed, and controlled the support during the near-Earth and deep space phases of the missions. The Launch Vehicle System was managed by the Lewis Research Center, and the contractors were the Convair Division of General Dynamics and McDonnell Douglas Corp. Unmanned launch operations at the Kennedy Space Center were supported by the Convair Division of General Dynamics.

Table 1. First- and second-generation Pioneers

Pioneer	Launched	Achievements
1	1958	Found extent of Earth's radiation bands
2	1958	Improved data on flux and energy levels of particles
3	1958	Discovered second radiation belt near Earth
4	1959	Extended measurements to within 59, 200 km of the Moon
5	1960	Obtained solar flare and wind data
6	1965	Continued to report data after traveling 5-1/4 billion km
7	1966	Reported data during solar cycle from widely separated points within 1. 125 AU of the Sun
8	1967	Reported data during solar cycle from widely separated points within 1. 09 AU of the Sun
9	1968	First spacecraft to transmit at three frequencies through the solar corona to measure the electron concentration

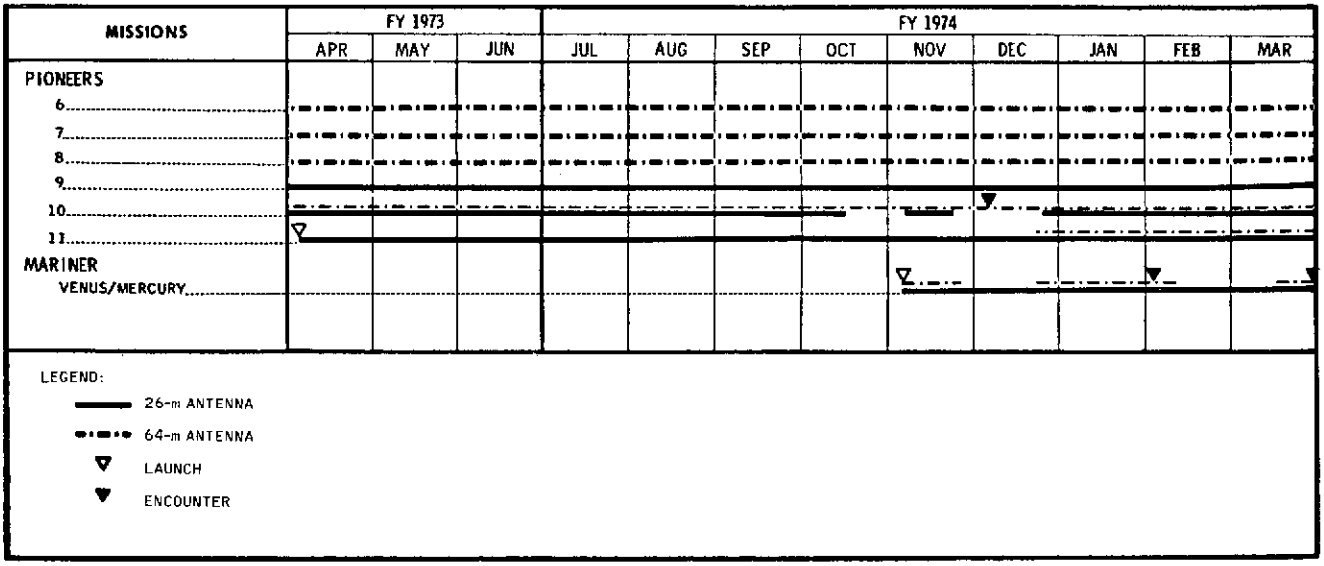


Fig. 1. DSN Support Schedule for Pioneer Spacecraft (Mariner is included to show scheduling problems)

II. TRACKING AND DATA SYSTEM

A. DSN FACILITIES AND SYSTEMS

DSN Facilities and basic systems are described in detail in Ref. 1.

B. JPL SUPPORT ORGANIZATION CHANGES FOR PIONEER MISSIONS

There have been two major changes in the Jet Propulsion Laboratory (JPL) organizations engaged in Pioneer support. The first involves the readjustment of the Ground Data System (GDS) responsibilities in accordance with new NASA Headquarters guidelines from the Office of Space Sciences (OSS) and the Office of Tracking and Data Acquisition (OTDA). The second involves the reorganization of the elements under Tracking and Data Acquisition (TDA) at the Laboratory. Reference 1 describes the JPL organization prior to these two changes.

The principal effect of the new OSS/OTDA guidelines was the separation of the computer processing necessary for the mission operations and mission analysis from the computer processing necessary for the operation of the DSN. As a consequence, the DSN is implementing a Network Control System (NCS) that will enable the DSN to phase computers out of the Mission Control and Computing Center (MCCC) by January 1975. Prior to this separation, an off-lab project such as Pioneer was able to look to the DSN as the single interface point for JPL support. The Pioneer Project's concern for having to deal with two interfaces, the DSN and MCCC, led to the establishment of a Pioneer support coordination function under the auspices of the Assistant Laboratory Director for Flight Projects. The resulting JPL organizations involved in Pioneer support are shown in Fig. 2. Responsibilities of the respective organizations are briefly as follows:

(1) Tracking and Data Acquisition (TDA): responsible for TDA planning, DSN Systems and Subsystem engineering, and operation of the DSN.

(2) Office of Computing and Information Systems (OCIS): responsible for the MCCC, associated supporting research, engineering, and operations.

(3) Flight Projects: responsible for the Ground Data System coordination and interface with the projects. This involves assuring that the interface between TDA and OCIS will result in a Ground Data System that meets project requirements.

(4) Telecommunications Division: responsible for DSN research and subsystem implementation.

(5) Mission Analysis Division: responsible for the navigation support of the Pioneer Project.

Figures 3 and 4 show the management structure in the Flight Projects Office and the Office of Computing and Information Systems, respectively.

In mid-1972, TDA underwent a major reorganization. The new organization (as it appeared at the time of Pioneer 11 launch) is shown in Fig. 5. Under the old organization described in Ref. 1, Deep Space Station (DSS) operations were under the Telecommunications division while DSN operations control was in a section in the old 400 organization directly under TDA. The reorganization combined DSS and DSN operations under a single office under TDA. In addition, the DSN System Engineer and mission support interface functions were combined into another single office.

C. TDA PIONEER PROJECT INTERFACE

In the new TDA organization the principal DSN interface with the Pioneer Project is the Tracking and Data System Manager, the DSN Manager for Pioneer (who also serves as the Assistant Tracking and Data System Manager) and the Network Operations Project Engineer (NOPE). The NOPE is in Network Operations, under DSN Operations, and combines the responsibilities of the Deep Space Network Project Engineer and Deep Space Station Operations Planning Project Engineer under the previous organization.

Because these two reorganizations occurred so close to launch, and to maintain continuity and assure proper preparation of the entire Ground Data System at JPL, which was no longer comprised of just DSN elements, the position analogous to the DSN Project Engineer under the previous organization was renamed Ground Data System Project Engineer and temporarily retained under the Tracking and Data System Manager. The resulting TDS organization is pictured for Pioneer 11 launch in Fig. 6.

A few months before Pioneer 11 launch, the DSN Manager for Pioneer accepted the position of Pioneer Support Coordination Manager in the Flight Projects Organization and a new DSN Manager was appointed. The majority of the DSN preparation responsibility for Pioneer 11 launch fell on the Ground Data System Project Engineer; the new DSN Manager for Pioneer concentrated on preparations for Pioneer 10 encounter.

An additional step taken to assure continuity of JPL support for Pioneer 11 launch was that the near real-time coördination responsibilities of the Network Operations Representative for Pioneer were temporarily expanded to include Mission Control and Computing Center scheduling activities.

Network operations interfaces for Pioneer are shown by Fig. 7.

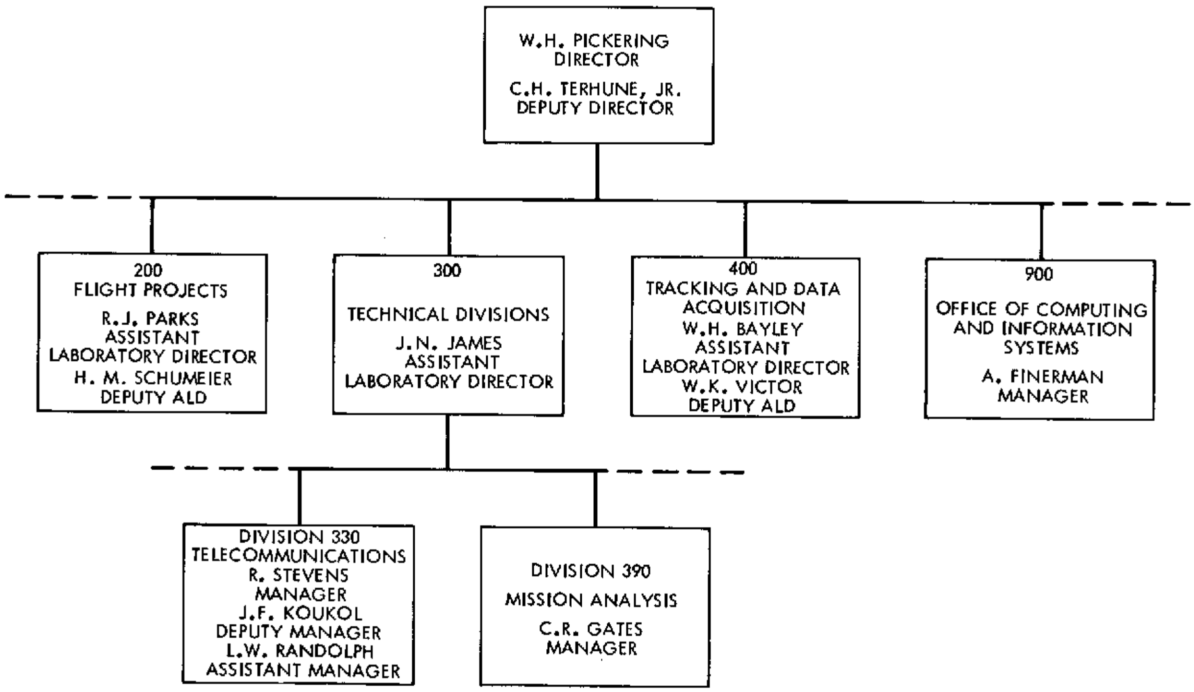


Fig. 2. Organizations supporting Pioneers 10 and 11

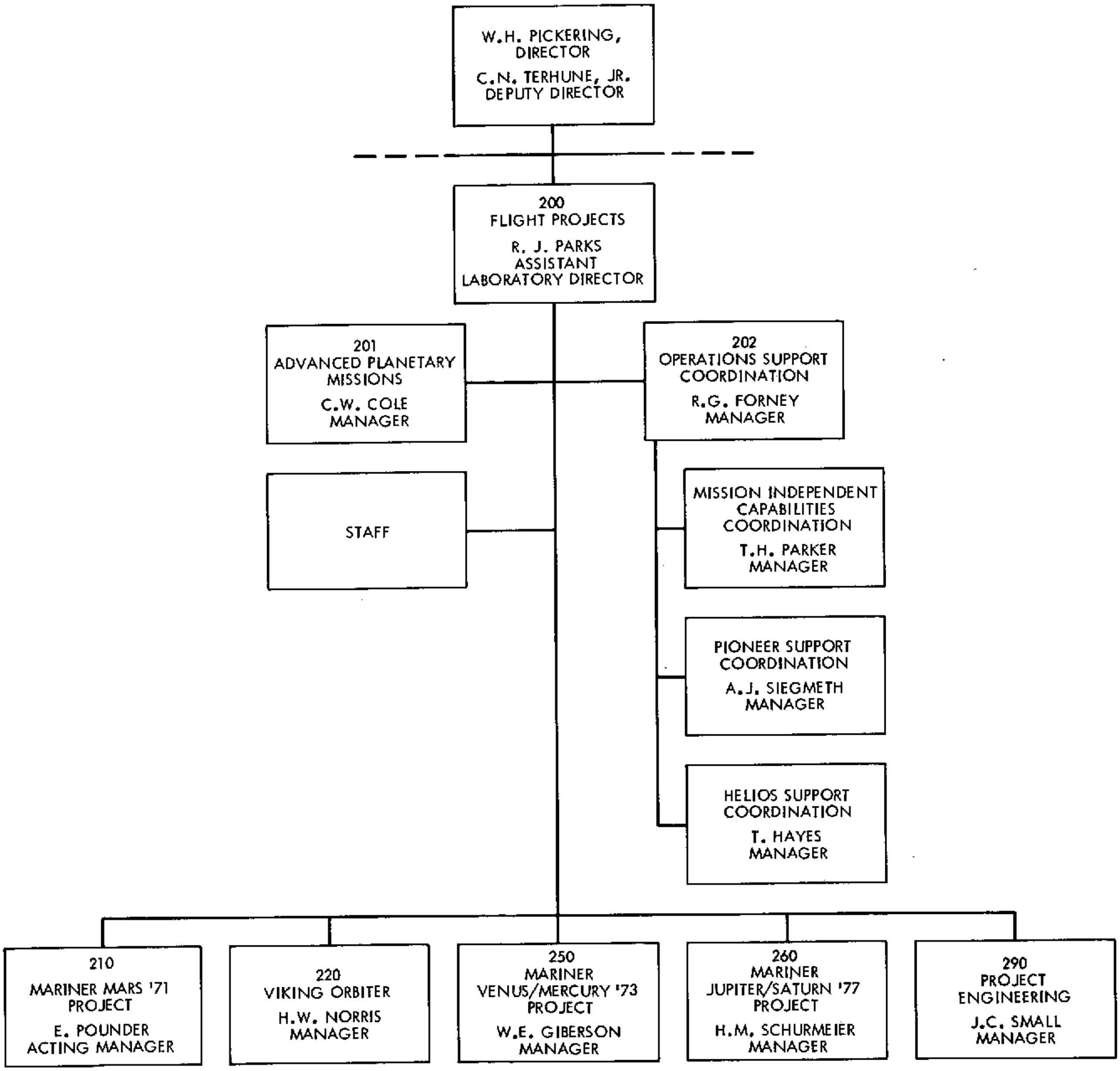


Fig. 3. Flight projects organization

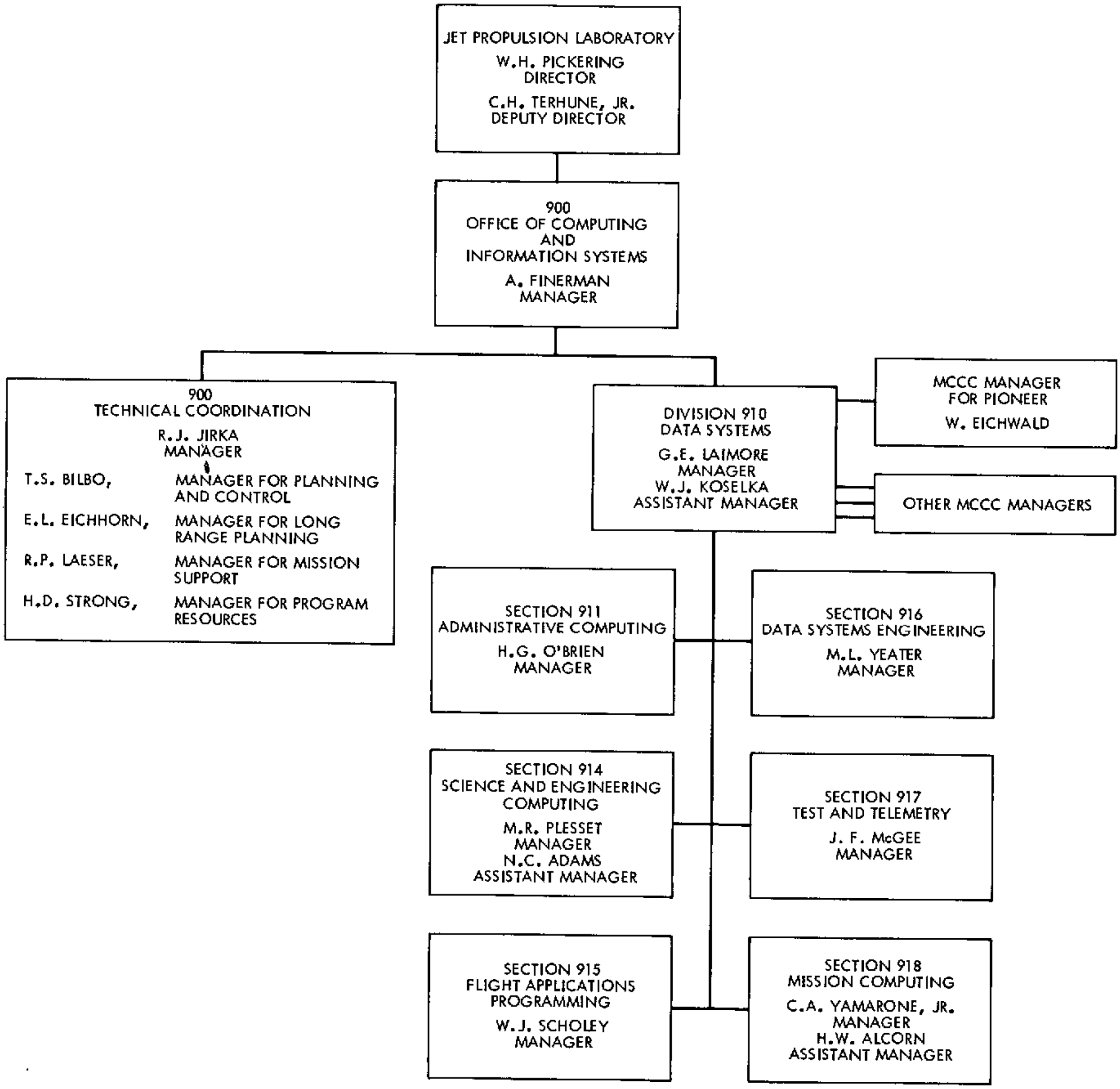


Fig. 4. Office of Computing and Information Systems

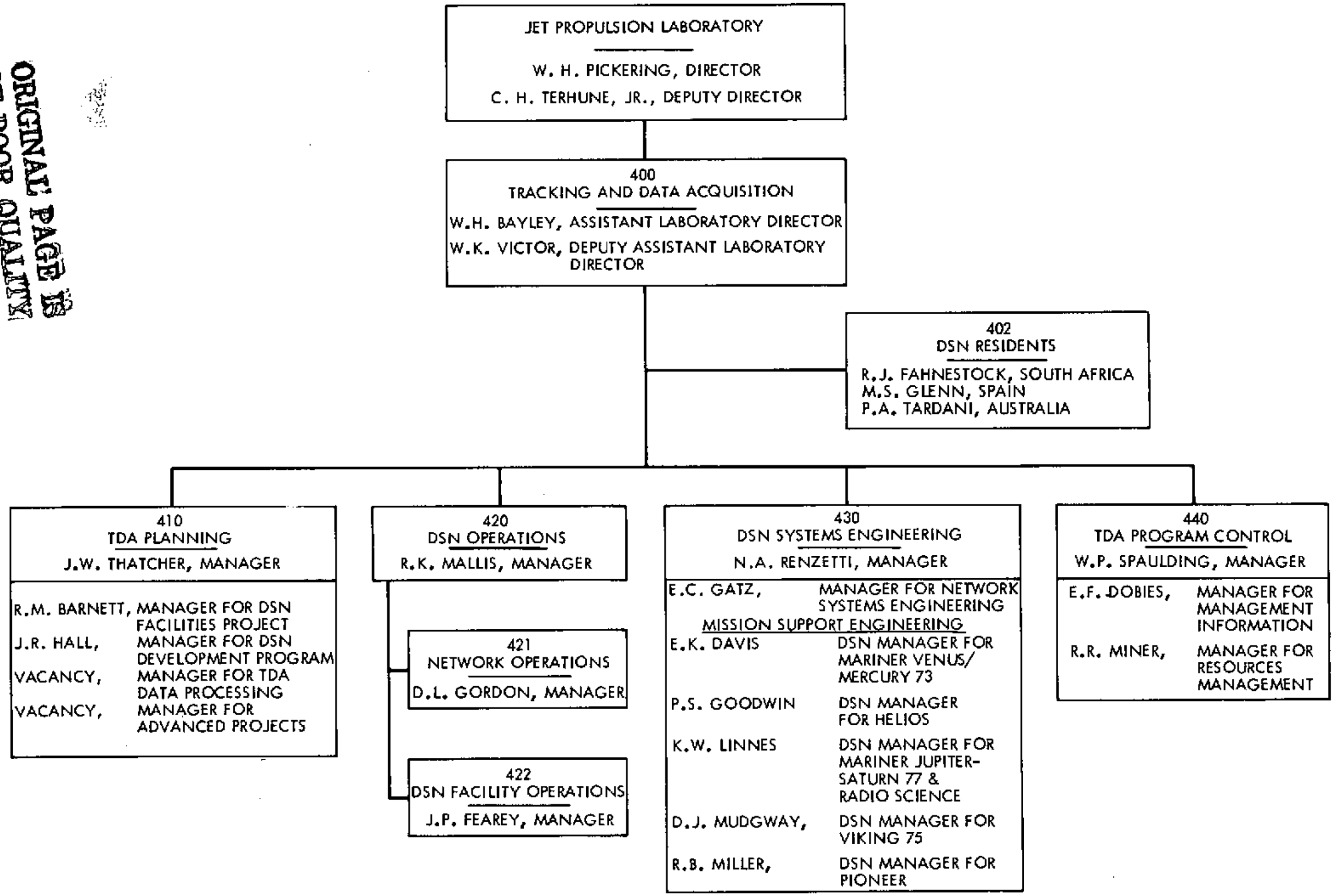


Figure 5. Tracking and data acquisition organization

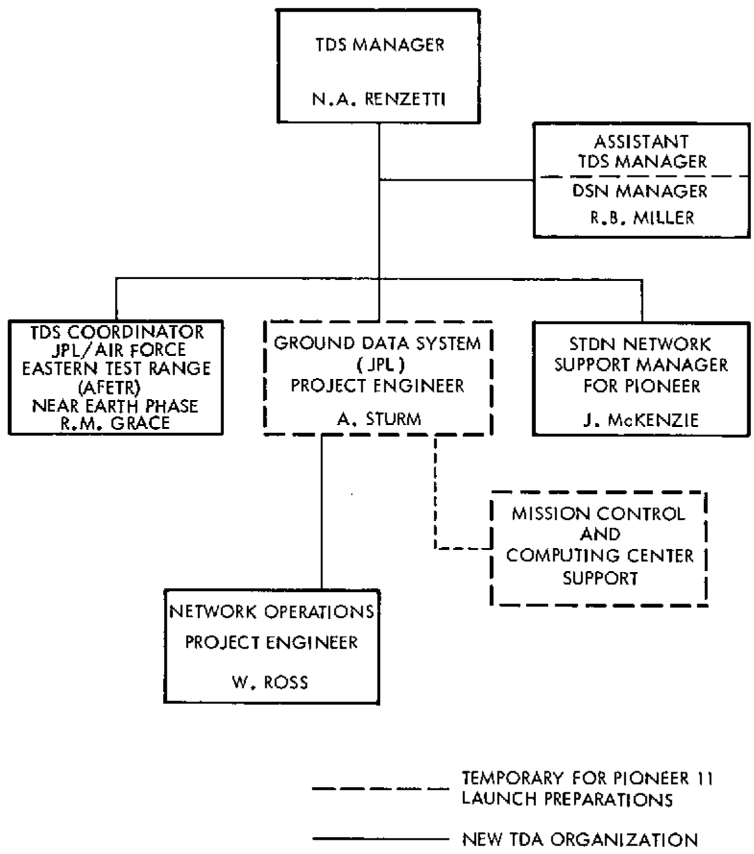


Fig. 6. Tracking and Data System organization for Pioneer 11 launch

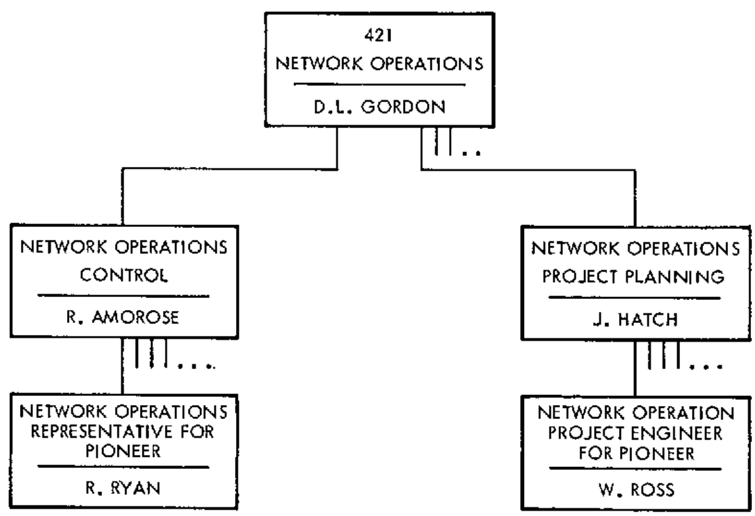


Fig. 7. Network Operations Pioneer interface

III. MISSION PROFILE

A. FLIGHT DESCRIPTION

1. Overall Trajectory

The powered flight trajectory for Pioneer 11 spacecraft was direct ascent from Cape Canaveral, Florida, in a direction 18 deg south of straight East. The interplanetary trajectory was near the ecliptic plane, with the spacecraft following a curving path about a billion kilometers long between the orbit of Earth and Jupiter. The path will cover about 160 deg going around the Sun between launch point and Jupiter.

After passage through the Asteroid Belt, between August 1973 and February 1974, the spacecraft will reach Jupiter in early December 1974. Periapsis and flyby trajectory were dependent upon analysis of the performance of Pioneer 10 spacecraft. Objectives of the Jupiter flyby trajectory of both spacecraft were: (1) to penetrate the Jupiter radiation belt; (2) to provide good viewing conditions for Jupiter before periapsis; (3) to obtain a short occultation for the spacecraft by Jupiter (less than 1 h; and (4) to provide a radius of closest approach to the center of Jupiter between 2 and 3 Jupiter radii.

After flyby, the spacecraft may be directed into solar orbit near Jupiter's orbit or on toward Saturn with arrival in 1980. Spacecraft controllers could accomplish any of the various mission options open to Pioneer 11 by varying the spacecraft's swingby trajectory around Jupiter: using the planet's gravity and orbital motion to change the spacecraft speed and direction. Figure 8 presents the general relationship of the Pioneer 11 trajectory to the Sun, Earth, Asteroid Belt, and Jupiter. Figure 9 is a simplified mission profile.

2. Midcourse Corrections

Trajectory corrections for Pioneer 11 were made April 10 and April 26, 1973, compensating for launch vehicle injection velocity vector errors. There was a precession maneuver on April 14.

3. Injection Velocities

The relative positions of Earth and Jupiter as they orbit the Sun permit a spacecraft to be launched every 13 months into a Jupiter-bound trajectory with a minimum of launch energy. The 1973 launch period was 22 days; the daily launch window averaged 45 min. This was a limitation associated with the direct-ascent powered-flight profile.

Under optimum conditions, injection velocities of approximately 14 km/s sufficed during this launch period. Velocity requirements were prohibitive throughout the remainder of the 13 months.

(The third stage, used with the Atlas/Centaur/TE 364 launch vehicle for the second time, made Pioneer 11 match Pioneer 10 as the speediest spacecraft. Peak velocity was 51, 800 km/h (traveling 800, 000 km a day.)

4. Environments

Equipped with field-and-particles and optical-type instruments, the spacecraft travel between Earth and Jupiter was to be mostly in the interplanetary solar-wind environment. Influences of the Earth's atmosphere ceased several hours after launch. The spacecraft was designed also to fly through the Asteroid Belt and the high-density Jupiter magnetosphere, where it was to explore the planet's trapped radiation particles.

5. Superior Conjunction

The relative positions of the Earth and spacecraft will place the spacecraft in a superior conjunction configuration versus the Sun and the Earth approximately 315 days after launch. Because the spacecraft was somewhat out of the ecliptic plane, the spacecraft/Earth line will not intercept the Sun, but will come within a few solar radii. In this configuration, the radio beam will be intercepted through the high-density part of the solar corona and will be influenced significantly by the plasma. Because of the closeness of the spacecraft to the Sun, DSN antennas will pick up, together with the spacecraft signal, solar high-frequency noise, which will degrade the received signal-to-noise ratio and can cut down considerably the quality and usefulness of the spacecraft-Earth telecommunication link. This condition will exist for one or two weeks.

6. Challenges and Hazards

a. Asteroid Belt. Pioneer 11 spacecraft, crossing Mar's orbit in July, is to reach the Asteroid Belt in August 1973 and remain in the belt for more than six months. With some 75,000 bodies larger than magnitude 20 in the belt, there is some possibility (considered slight since Pioneer 10 had no difficulty) that the spacecraft could collide with one of the asteroids or meteoroids — the largest of which is Ceres with a diameter of 768 km. Onboard sensors were designed to detect these bodies, which travel 48,000 km/h relative to the spacecraft. This hazard could result in a loss of the spacecraft high-gain antenna radio link. Should this occur, the DSN would attempt to acquire spacecraft signals radiated by the medium-gain or omnidirectional antenna.

b. Jupiter Radiation Belts. The electrons, protons, and magnetic field in the Jupiter radiation belts have a much higher intensity and flux density than the Van Allen Belt, through which the spacecraft passed the first day of flight. The possibility has been noted that the crystal oscillators of the spacecraft transponder will slightly detune as the spacecraft traverses the Jupiter radiation belt. The high-intensity Jupiter magnetosphere can also change the polarization ellipticity of the spacecraft signal radiated toward Earth. In addition, the spacecraft flying in the close vicinity of Jupiter will undergo an abrupt velocity change that will cause within 2 or 3 h a considerable change in the doppler shift. This shift has to be tracked by the spacecraft receiver and by the DSN.

c. Jupiter Flyby. The physical nature of Jupiter creates many challenges. Jupiter's average distance from the sun is 5 AU, equivalent to approximately 75×10^7 km. Its mass is equivalent to 318 times the Earth's mass and comprises 70% of all planetary mass. Jupiter's diameter (approximately 71,387 km) is 11 times the Earth's diameter, although density is approximately one-fourth of the Earth's density and its fastest rotation is 9 h and 50 min. The assumption is that Jupiter's upper atmosphere is composed of hydrogen, helium, ammonia, and methane, and it is an intense radio noise source at decametric frequencies. However, the noise drops considerably toward the S-band frequency range. The typical cold sky system noise temperature of the Goldstone DSCC 64-m antenna station is 25 K. Movement of the antenna in the direction of Jupiter increases the system noise temperature approximately 5 K. This increase can cause a telemetry signal-to-noise degradation of around 0.5 dB. The dense magnetosphere of the planet is caused by an extremely high magnetic field, which may be as high as 5×10^{-4} T (5 G).

B. SCIENTIFIC OBJECTIVES AND EXPERIMENTS

Pioneer 11 spacecraft carried 12 special scientific instruments to conduct 14 experiments and make 20 measurements to produce findings about Jupiter, the Asteroid Belt, and the heliosphere. This was one more experiment and one more instrument (a flux-gate magnetometer) than scheduled for the Pioneer 10 mission. Dr. Norman Ness, NASA – Goddard Space Flight Center, Greenbelt, Md., is the principal investigator for this magnetic field experiment.

The experiment was designed to tell whether Jupiter's magnetic field is more like the Earth's or the Sun's field, a question that bears directly on the origin of the solar system. Jupiter's radio emissions have suggested a possible four-pole rather than a two-pole configuration for the Jovian field. If the spacecraft passes through the same field line as that occupied by Jupiter's moon, Io, the experimenter hopes to gather data on particle and electrodynamic effects produced by Io on radio emission from Jupiter.

The instrument will be able to continuously measure the magnetic field along the spacecraft trajectory from about 12.6 Jupiter radii to the point of closest approach. It consists of two dual-axis sensors and their electronics. Each sensor is composed of a ring core, a magnetic multivibrator, a frequency doubler, and two phase-sensitive detectors. It weighs 26 g and uses approximately 0.36 W of power.

For descriptions of the other 11 instruments and the experiments they support refer to pp. 28-41 of Ref. 1.

Total weight of the scientific instruments aboard the Pioneer 11 spacecraft was approximately 30 kg.

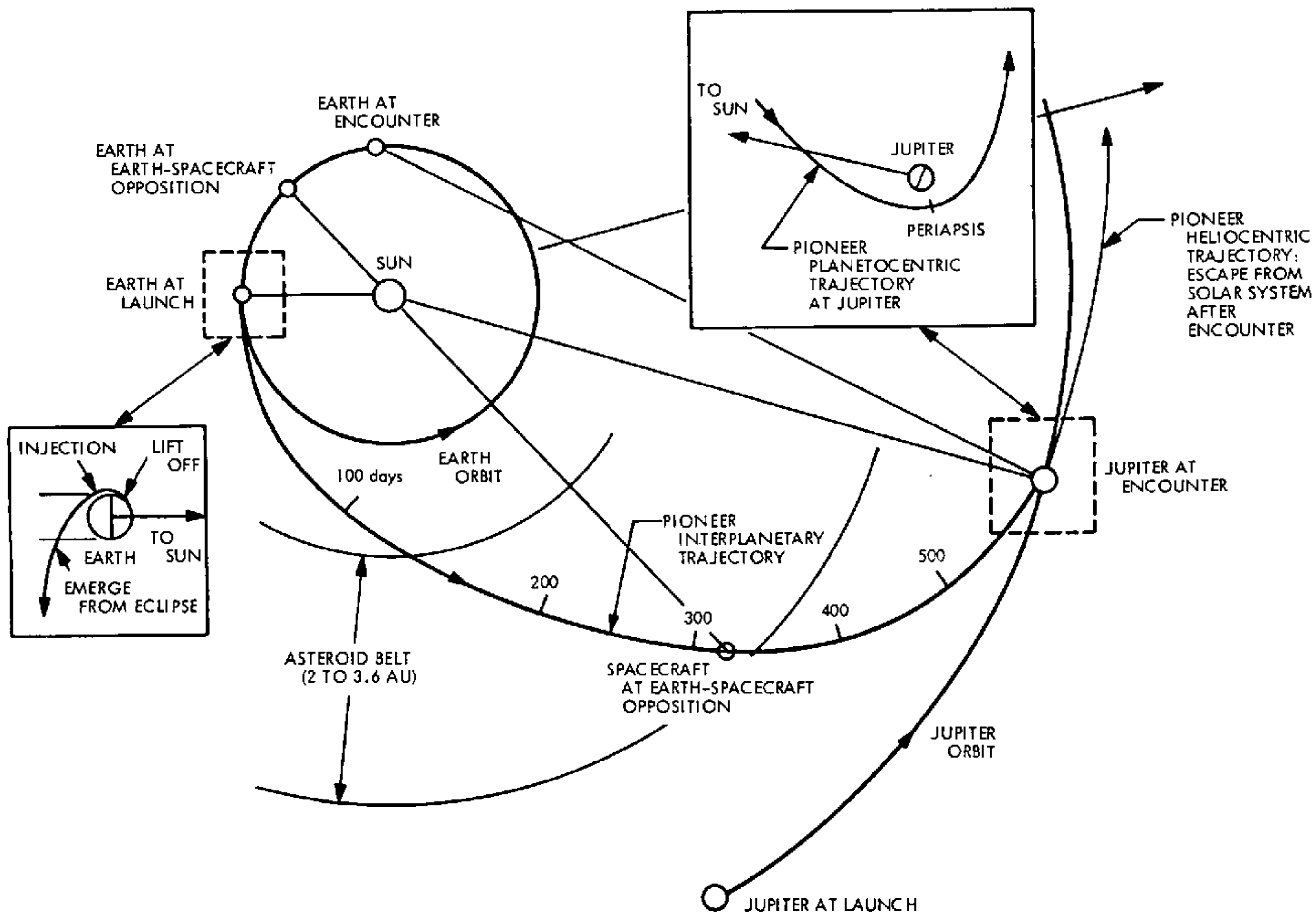


Fig. 8. Ecliptic projection of typical Pioneer 11 trajectory

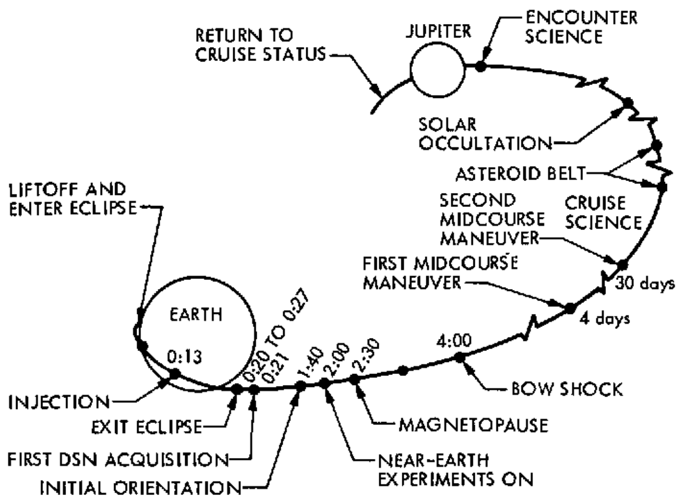


Fig. 9. Pioneer 11 Missile profile

IV. LAUNCH VEHICLE AND SPACECRAFT CONFIGURATIONS

Reference 1 provides detailed information on launch vehicle and spacecraft configurations for Pioneer 10. That mission's configurations and those for Pioneer 11 were similar. The differences between the two missions were: (1) the Centaur used for Pioneer 11 had a pulse modulation system rather than a frequency modulation system; (2) there was no telemetry from the Pioneer 11 Atlas – the data was transmitted via the telemetry link from Centaur to Earth; (3) the Pioneer 11 third stage had an S-band transmitter for radio telemetry, and the Pioneer 10 a P-band transmitter.

V. TRACKING AND DATA ACQUISITION REQUIREMENTS AND TDS SUPPORT PLANNING

A. CONTROL

Critical phases of the Pioneer 11 spacecraft flight – including launch, early flight, and midcourse maneuvers – required control from the Pioneer Mission Support Area (PMSA) at the Jet Propulsion Laboratory in Pasadena. Other mission control was maintained at the Pioneer Mission Analysis Area (PMAA) at Ames Research Center.

B. DOCUMENTATION

All project requirements on the tracking and data system were published in detail in the Support Instrumentation Requirements Document (SIRD) (Ref. 2). A NASA Support Plan (NSP) was prepared to respond to the SIRD (Ref. 3).

Project requirements and TDS support plans are summarized for the near-Earth and deep-space phases in the remainder of this section.

C. LAUNCH AND FLIGHT CONSTRAINTS

The Project required TDS to plan support of a launch during the Jupiter opportunity from April 5 through April 26, 1973. (Periods when the relative position of Earth and Jupiter permit a spacecraft to be launched into a Jupiter-bound trajectory with minimum energy occur at 13-month intervals.) The trajectories were in a more southernly direction than those for Pioneer 10.

The launch azimuth constraint determined the boundaries of the near-Earth trajectories. The shorter Jupiter trip times were favored over the longer ones. Trajectories that brought the S-band radio beam too close to the solar corona were eliminated. This measure was necessary because of the degradation of the telecommunications link's signal-to-noise ratio caused by solar noise. In addition, efforts were made to share the available resources of the DSN between the Pioneer 11 Mission and other missions in various stages of progress. The view limitations of some onboard Pioneer 11 scientific instruments and the objective of having an S-band signal occultation by Jupiter were factors that determined the angle of the aiming point at Jupiter and its position in relationship to the planet's spin axis and equator. To reach the planned Jupiter flyby aiming point within a predetermined dispersion, two or possibly three midcourse or trim maneuvers were expected to be necessary to alleviate the aiming errors of the launch vehicle.

Figures 10 through 16 present data detailed in advance of launch.

D. NEAR-EARTH PHASE

Near-Earth phase (NEP) tracking and data acquisition required the participation of facilities of the Air Force Eastern Test Range (AFETR), Goddard Space Flight Center (GSFC), Kennedy Space Center (KSC), DSN, Spaceflight Tracking and Data Network (STDN), and NASA Communications Network (NASCOM). Required were the telemetry and radio metric tracking of the three stages of the launch vehicle and the collection of real-time telemetry from the spacecraft during powered flight.

Launch vehicle-generated information was necessary to monitor the performance of the launch vehicle system to determine any deviations from normal performance predictions and to generate a solar orbit injection velocity vector. This near-real-time orbit was necessary for the DSN to obtain antenna angle and frequency predictions for efficient first-signal acquisition. The real-time spacecraft telemetry furnished by the near-Earth phase tracking facilities was provided for the use of the Project's Mission Operations Systems team in monitoring the powered flight performance of the spacecraft, in checking for normalcy, and preparing for the transmission of important commands after the first two-way signal acquisition by the DSN.

1. Data Types and Support Classifications

With data requirements separated for convenience into three types — metric data (C-band and S-band), launch vehicle telemetry, and spacecraft telemetry — there were five major uses for the data required by Project. These were: (1) the quick establishment of the mission's normalcy; (2) the determination of minute-by-minute status of the flight; (3) to assist the DSN, STDN, and AFETR in acquiring the vehicle and/or spacecraft; (4) to assist the Project in making decisions concerning a nonstandard mission; and (5) to enable postlaunch analysis.

The requirements for metric and telemetry data support were classified according to their importance with respect to successful accomplishment of the mission. The three classes of requirements were defined by the Project Office as:

(1) Class I: those requirements essential to ensure accomplishment of primary mission objectives, i.e., mandatory requirements that, if not met, might result in a decision not to launch.

(2) Class II: those requirements needed to accomplish all stated mission objectives.

(3) Class III: those requirements that provide the ultimate in desired support, i.e., support that would provide the capability of achieving the objectives at the earliest time in the mission program.

2. Near-Earth Requirements and Configuration

The tracking and telemetry data requirements during the Pioneer 11 near-Earth flight phase are presented in Tables 2 and 3.

Using the overall tracking coverage data provided as indicated in Table 2, the Real-Time Computer System (RTCS) provided:

(1) Transfer orbit elements, and Jupiter mapping based on C-band tracking data after injection.

(2) DSIF predicts to DSS 51 and the STDN Ascension Island (ACN) site based on the orbital elements above.

(3) Spacecraft orbital elements, Jupiter mapping, and I-matrix based on S-band tracking data after separation.

(4) DSIF predicts to DSS 51 and the STDN ACN site based on the spacecraft orbital elements above.

(5) Centaur postdeflection orbital elements and I-matrix based on C-band tracking data after the deflection.

3. Near-Earth TDS Configuration

Tables 4 and 5 indicate the near-Earth TDS (NETDS) resources to be used in support of Pioneer 11; Tables 6 and 7 indicate what requirements were supported by these resources.

The details of the stations' configuration are available in Refs. 4 and 5.

4. Trajectory and Launch Window Characteristics

a. Ascent Trajectory Characteristics. The desired spacecraft direct ascent trajectory was accomplished by an Atlas/Centaur burn followed by a TE 364-4 solid propellant third-stage burn. At main engine cutoff (MECO), the vehicle altitude varied from 160 to 176 km. There was an 85-s coast between Centaur MECO and TE 364-4 ignition. Vehicle altitude at third-stage burnout varied from 230 to 361 km, depending on path angle at MECO.

The launch azimuth was constant throughout the launch opportunity at 108 deg. Beginning in the Atlas Sustainer Phase (147 s), the trajectories were yawed by guidance to obtain the necessary final target vector. (Geometric azimuth or amount of yawing was defined as the corresponding planar launch azimuth the vehicle would fly to reach the final target vector, instead of the 108-deg launch azimuth and yawing.)

Geometric azimuths for Pioneer 11 were between 107.9 and 115.6 deg. The declinations of the target vector ranged from -32.93 to -37.21 deg.

Figure 17 provides typical Earth tracks for the Pioneer G launch opportunity. Table 8 provides basic launch trajectory characteristics for each Pioneer G launch day.

b. Launch Window Characteristics. The geometric azimuth varied up to a maximum of about 2 deg through a daily launch window during the maximum 22 days feasible for launching Pioneer G. These days are from April 5 through April 26, 1973. Launch days from April 5 through April 18 had 45-min windows and launch days from April 19 through 26 had 30-min windows.

With the injection path angle at third-stage burnout becoming larger because the vehicle was launched later in the daily window, vehicle altitude became greater at third-stage burnout as well. This allowed better near-Earth TDS station view.

5. Flight Events

Key flight events for the near-Earth phase are listed in Table 9.

The Centaur MECO varied a maximum of about 8 s for all trajectories considered (709 to 717 s).

a. Sequence of Events. Seventy seconds following MECO, the Centaur third-stage spacecraft configuration spun up, with the impulse to separate Centaur occurring 2 s later. Separation was provided by venting residual helium through canted nozzles mounted at the aft end of the Centaur tank, which would remain in an elliptical Earth orbit. No impulse was imparted to the third stage during separation. Third-stage ignition occurred at MECO plus 85 s, and the third stage burned for approximately 44 s. This was a solid-propellant fixed-impulse burn. Separation of the spacecraft from the third stage occurred 100 s after third-stage burnout.

6. NETDS Potential Constraints

All Class I requirements on the near-Earth phase were met with the planned resources available for the Pioneer G Mission. In many cases, there was at least partial overlap of stations that were satisfying a requirement. To meet all the Class I NETDS requirements, however, certain stations had to be available for support. A matrix of stations required for each of these NETDS requirements is provided in Table 10.

If any of the stations required in Table 10 were not available for launch, there could be a potential constraint. This held true especially for the Antigua supporting stations and the ship Vanguard, which covered critical vehicle events and/or data intervals.

7. NETDS Expected Station Coverage

Estimates made on C-band and S-band metric data and launch vehicle and spacecraft telemetry data coverage took many factors into account. The most important were station masks, aspect angle, system characteristics, signal strength, and past performance. Detailed estimates of data coverage for metric data, launch vehicle telemetry data, and spacecraft telemetry data are provided in Tables 11 through 13. These tables are a composite of the expected near-Earth TDS station coverage throughout the Pioneer G launch window. For most stations, the expected coverage would not vary more than 20 s because of the fairly narrow range of outgoing declinations (32.93 through 37.21) finally selected for the Pioneer G Mission.

Estimates made for the support by Vanguard C-band and telemetry stations were based on one of three ships' positions. These ship locations in latitude and longitude were as follows: 5.00 and 313.00 deg, 7.00 and 315.0 deg, and 9.00 and 316.0 deg. Final optimum positioning of the ship by GSFC for each launch day was expected to provide slightly different estimates of coverage than provided here.

Expected C-band radar metric data support consisted of radar data generated by the AFETR Merritt Island, Cape Canaveral, Patrick, Grand Turk, Antigua, and Ascension radars and STDN C-band radars at Bermuda, Tananarive, and the NASA Ship Vanguard. High-speed data were transmitted from Merritt Island, Cape Canaveral, Patrick, Grand Turk, Antigua and Bermuda. The other sites transmitted data by 100-wpm teletype.

All data were transmitted to the AFETR Real-Time Computer System where they were processed and used to compute acquisition data and an early definition of the Centaur, TE 364-4, and spacecraft orbits. A one-hour span of DSS 51 and ACN S-band radio metric data was also sent to the RTCS to obtain an early estimate of the spacecraft orbit.

Stations expected to support the launch vehicle S-band telemetry requirements during the NEP were Building AE/STS, CIF, Bermuda, Antigua, Vanguard, RIA, Ascension (AFETR), Ascension (STDN), and Tananarive.

RIA support was expected to cover at least the critical vehicle events (third-stage burn, spacecraft separation, and YO deployment) supported by the Vanguard. The RIA was severely range limited when tracking the TE 364-4 telemetry link.

Antigua covered the MECO interval, but not the third-stage burn for the entire Pioneer G launch window.

Several stations would have geometric view of the vehicle, but might lose track because of the weak signal at that range. These stations are indicated in Table 14.

E. DEEP-SPACE PHASE

1. Requirements

a. Tracking. Project tracking requirements of the DSN networks follow, in brief.

Two-way doppler data were continuous from initial acquisition by the DSN to the first midcourse maneuver or 5 days, whichever was first: for at least one horizon-to-horizon pass per day thereafter through the remaining midcourse maneuvers (estimated to be 2) at 15- to 20-day intervals; after final maneuvers, for one horizon-to-horizon pass per day for ten days followed with two such passes per week for three weeks.

Cruise phase requirements were for two horizon-to-horizon passes for two weeks — one on a day with a reorientation maneuver and one on a day without a reorientation maneuver. This last requirement was a minimum and assumed tracking data were available during the reorientation maneuver and no significant perturbation of trajectory caused by the reorientation maneuver.

At least one horizon-to-horizon pass per day, signal-to-noise ratio permitting, was required between 30 days prior to and 30 days after solar conjunctions.

During the encounter or flyby phase, the requirement was for two horizon-to-horizon passes per week from encounter minus 30 days to encounter plus 30 days, with continuous tracking from encounter minus 10 days to encounter plus 10 days.

The sample rate required was to be 1 point per 60 s, except as follows:

(1) One point per second during midcourse maneuvers.

(2) One point per 10 s from Ascension first acquisition to acquisition plus 1 h.

(3) One point per 10 s during DSS 51's first pass.

b. Telemetry. For the purpose of monitoring spacecraft performance, engineering evaluation, failure detection, and scientific data, the Project set forth requirements to support the primary mission objective.

Continuous coverage by the DSN 26-m-diam antenna network was required from initial acquisition to Jupiter encounter plus six months. The 64-m-diam antenna network was required to support at least one horizon-to-horizon tracking mission per week during the same period. And, during critical mission events, the 64-m-diam network was to provide continuous coverage with suitable pre- and postcoverage.

Until Jupiter encounter plus six months to the limit of receipt of the downlink signal, the DSN was expected to give daily coverage as required.

2. Support Plans

The DSN planned to furnish almost 24-h/day continuous support from any three continuous-view combinations of the following 26-m-diam antenna stations: DSSs 11, 12, 42, 44, 51, 61, and 62. As Jupiter flyby neared and during the flyby phase, the 64-m-diam antenna subnet of DSSs 14, 43, and 63 was to provide the best assurance of near-optimum data return using the Network's most advanced resources.

Because of Jupiter's position versus the inclination of the Earth's spin axis, the geocentric declination angle of the Pioneer 11 Mission would be quite low, at least during the first part of the Jupiter transfer trajectory.

At injection, the geocentric declination angle would be approximately minus 32-1/2 deg, and at Jupiter encounter the declination would be minus 19 deg. Because of the low negative declination angles, the view of the spacecraft from the DSN stations located in the southern hemisphere would be more favorable than the view from the northern hemisphere locations. The first acquisition station's (DSS 51's) set time would be approximately 2 h before the Ascension Island station loses view of the spacecraft. With a small time gap between the DSS 51 (Johannesburg Deep Space Communications Complex (DSCC)) set and the DSS 11 (Goldstone DSCC) rise, it was planned that the Ascension Island station would deliver the telemetry information. The view period of DSS 11 would be in the vicinity of 7 h, but the view period of DSS 42 at Canberra, Australia, would be more than 14 h long. A good overlap between the DSS 51 (Johannesburg) rise and the DSS 42 (Canberra) set would also exist.

The lengths of the view periods of the northern hemisphere stations would increase gradually. One hundred days after launch the declination angle would decrease from minus 33 deg to minus 24 deg. DSS 11 at Goldstone DSCC would have at that time a maximum view period of almost 10 h.

The low elevation angles of the northern hemisphere stations together with short station overlaps could, during a few hours, cause a deterioration of the signal-to-noise ratio of the telemetry signal. At Jupiter encounter, the DSN planned to use the 64-m-diam antenna subnet: DSS 14, Goldstone DSCC; DSS 43, Canberra; and DSS 63, Madrid. The closest approach to Jupiter with a spacecraft/Jupiter center range of Jupiter radii equivalent of 210,000 km would be adjusted such that this periapsis point would be reached around the middle of the 5-h overlap between the Goldstone DSCC and Australian stations. Thus, the most important event of the missions would be supported by two 64-m-diam antenna stations. This configuration would enhance the reliability of data return.

Because of the large relative velocity changes between the Earth and the Pioneer 10 and 11 spacecraft, the uplink doppler shifts would be much larger than ever experienced by the Deep Space Network on previous planetary flights. The doppler shift would start at minus 70 kHz and move between two boundaries of minus 250 kHz and plus 130 kHz. The DSN planned to furnish additional crystal oscillators to all stations to handle these unusual doppler excursions. Because of the large gravitational forces of the Sun's biggest planet Jupiter, the doppler shift would change from minus 250 kHz down to minus 410 kHz; in a few hours, it would swing back around to minus 200 kHz.

The 26-m-diam antenna stations would reach the 2048-bit/s telemetry rate under the most favorable conditions of the S-band telecommunications link at 140 days after launch with a geocentric range of 1.3 AU. At 230 days after launch, 512 bits would be obtained, and at Jupiter encounter the 26-m-diam antenna stations would be able to support a 128-bit/s telemetry rate. The 64-m-diam antenna stations would increase the data return considerably. With the availability of these facilities for tracking and data acquisition, telemetry bits rates of 1024 bits/s can be obtained after 280 days of flight and up to 700 days. This time frame would include the Jupiter encounter. The shown optimum telemetry bit rates can be obtained only when the spacecraft high-gain antenna points exactly at the Earth and the DSN antenna at the spacecraft.

F. GROUND COMMUNICATIONS

1. Requirements

Project communication requirements in the near-Earth phase were for voice, teletype (TTY), and high-speed data (HSD) circuits within the elements of the TDS and among TDS facilities and the Project launch operations facilities that were adequate to conduct test and launch operations. Ground Communications Facility requirements as presented in the Support Instrumentation Requirements Document included voice high-speed data and teletype circuits.

NASA Communications Network/Ground Communications Facility (NASCOM/GCF) operating terminals for the near-Earth phase were required at:

(1) JPL-GCF Switching Center, Compatibility Test Area (CTA) 21, and Simulation Center.

(2) Cape Kennedy Air Force Station: DSS 71, Real-Time Computing System, and Building AE.

(3) Goddard Space Flight Center, Network Operations Control Center.

(4) Kennedy Space Center, Central Instrumentation Facility for the AFETR.

(5) Ames Research Center (ARC), Remote Information Center (RIC).

2. Support

Except for the JPL-Goldstone DSCC circuits, all circuits between the JPL and Deep Space Stations, STDN stations, and other stations supporting Pioneer 11 were supplied to the DSN by NASCOM. The communications network shown in Fig. 18 represents the types, quantities, and routing of circuits used in support of Pioneer 11's test and near-Earth phases. Figure 19 depicts the circuits used in support of the spacecraft's deep space phase up to the completion of the midcourse maneuvers.

The voice, teletype, and HSD systems were employed in support of Pioneer 11 in basically the same manner in which Pioneer 10 spacecraft was supported. The use of the NASCOM/GCF/HSD system was the prime means of transferring data between the NCS and supporting stations.

a. High-Speed Data System. The NASCOM/GCF/HSD system provided a 4.8 kbps synchronous high-speed data transfer capability. HSD interface with STDN stations was 7.2 kbps. HSD system acceptance tests were conducted with the Pioneer 11 prime support Deep Space Stations and with the ARC Remote Information Center. The tests were successful in demonstrating that the tested stations could operationally support Pioneer 11 using the 4.8 kbps NASCOM/GCF HSD system.

b. Mission-dependent HSD System Interface. One mission-dependent interface between the Pioneer Project and the GCF HSD system was required to support Pioneer 11. This was the NASCOM/GCF/HSD capability established for Pioneer 10 between the JPL and the ARC RIC.

c. Support HSD Configuration. The GCF, Pioneer Project, and NASCOM agreed on the HSD configuration and utilization plan for the Pioneer 11 launch phase shown in Fig. 20.

d. Augmented Support Requirements. Table 15 identifies varying degrees of augmented communication coverages that were to be provided in support of mission-critical periods. Actual coverages were to be identified by a specific time frame within the weekly GCF Circuit Schedule message, or by interoffice memos as actual requirements would dictate.

Table 2. Project requirements for C-band (radar) and S-band (radio) metric data for the near-Earth phase

Vehicle and System[a]	Class I	Class II
Centaur C-band	Launch (L) to Centaur MECO + 60 s	AOS[b] to LOS[c] for Cape Kennedy (1. 16), Grand Turk (7. 18), Antigua (91. 18) and Tananarive.
TE 364-4 C-band	MECO through YO[d] deployment	AOS to LOS for Patrick (0. 18), Bermuda (67. 18), and Ascension (12. 16)
Spacecraft S-band	1-h interval starting at initial two-way acquisition[e]	

[a]All data transmitted to Real-Time Computer System.

[b]Acquisition of signal.

[c]Loss of signal.

[d]Despin counterweight.

[e]Either DSS 51 or Ascension (STDN) depending on initial acquisition station. This interval was assumed to be a Class I interval even though not specified because of the importance of these data for validating two-way lock, initial spacecraft orbit, and commanding activities.

Table 3. Project requirements for launch vehicle and spacecraft telemetry data

Stage and Link	Class I	Class II	Comments
Atlas (2215.5 MHz)	Time of event (T)-75 min to T+5 min		T-75 min to T-5 min during periods of radiation only
Centaur (2202.5 MHz)	T-75 min to Antigua LOS	AOS to LOS from stations at Bermuda, Vanguard[a], Ascension, and Tananarive	T-75 min to T-5 min during periods of radiation only
TE 364-4 (2250.5 MHz)	T-75 min to YO deployment	AOS to LOS from stations at Bermuda, Ascension, and Vanguard	T-75 min to T-5 min during periods of radiation only
Spacecraft (2292.0 MHz)	Start of spacecraft countdown to launch T-10 min (DSS 71 support)	T-10 min until initial two-way acquisition	Class II requirement includes AOS to LOS from DSS 71, Bermuda, Antigua, Vanguard, and Ascension (STDN)

[a] One range instrumentation aircraft (RIA) is scheduled to backup the support of the Vanguard during the critical third-stage burn and spacecraft separation interval.

Table 4. Tracking resources for generation of C-band radar metric data

Station	Station symbol	System type	Comments
Merritt Island	MIL	TPQ-18	
Cape Kennedy	CKE	FPS-16	Range safety
Patrick AFB	PAT	FPQ-6	
Grand Turk	GTK	TPQ-18	
Bermuda	BDA	FPQ-6	
Antigua	ANT	FPQ-6	
Vanguard	VAN	FPS-16(V)	NASA ship
Ascension (AFETR)	ASC	FPS-16	
Tananarive	TAN	FPS-16(V)	

Table 5. S-band telemetry resources

Station	Station symbol	System type	Comments
Spacecraft Compatibility/ Monitor Station	DSS 71	DSN	Cape area
Central Instrumentation Facility	CIF[a]		Cape area
Building AE	AE	STS[b]	Cape area
Merritt Island	MIL	USB[c]	
Bermuda	BDA	USB	
Antigua	ANT	TAA-8A	
Vanguard	VAN	USB	NASA ship
Range Instrumented Aircraft	RIA		
Ascension (AFETR)	ASC	TAA-3A	
Ascension (STDN)	ACN	USB	
Johannesburg (DSN)	DSS 51	DSN	
Tananarive	TAN	STDN	

[a]Central Instrumentation Facility.

[b]Satellite Tracking Station.

[c]Unified S-band.

Table 6. Summary of expected metric data support

Station	C-band Centaur (Class)	C-band TE 364-4 (Class)	S-band data after spacecraft separation (Class)	Comments
Merritt Island	I			
Patrick AFB		II		
Cape Kennedy	II			Range safety
Grand Turk	II			
Bermuda		II		
Antigua	I, II			
Vanguard		I		
Ascension (AFETR)		I, II		
Ascension (STDN) (USB)			I	
DSS 51 (DSN)			I	
Tananarive	II			Postretro-fire of Centaur

Table 7. Summary of expected telemetry data support of S-band telemetry requirements

Telemetry site[a]	Launch vehicle telemetry Atlas (Class)	Launch vehicle telemetry Centaur (Class)	Launch vehicle telemetry TE634-4 (Class)	Spacecraft S-band Telemetry (Class)
DSS 71 (DSN)				I, II
AE/STS	I	I	I	
CIF	I	I	I	
Merritt Island (USB)				II
Bermuda (USB)		II	II	II
Antigua (AFETR)		I	I	II
Vanguard (ship)		II	I	II
RIA (aircraft)		footnote b		
Ascension (AFETR)			II	
Ascension (STDN) (USB)				I, II
DSS 51 (DSN)				I
Tananarive (STDN)		II		

[a]The real-time transmission of spacecraft telemetry data (Class III) is desired from Merritt Island, Bermuda, Vanguard, Antigua, and RIA.

[b]The RIA was a backup for the Vanguard and, if needed, would have the same class of requirement for Centaur, third stage, and spacecraft telemetry data as the Vanguard.

Table 8. Pioneer G daily launch window trajectory characteristics

Launch date (GMT)	Arrival date (GMT)	Targeting window (GMT) Open (h:min:s)	Targeting window (GMT) Close (h:min:s)	Approximate geometric launch azimuth, deg	Target declination, deg	Range of relative path angles at injection, deg
4-5-73	12-5-74	26:11:00	26:56:00	111.9	-34.90	5.44 to 12.38
4-6-73	12-5-74	26:3:00	26:48:00	111.0	-34.55	5.39 to 12.35
4-7-73	12-5-74	25:55:00	26:40:00	110.5	-34.22	5.33 to 12.31
4-8-73	12-5-74	25:48:00	26:33:00	110.1	-33.91	5.41 to 12.42
4-9-73	12-5-74	25:40:00	26:25:00	109.3	-33.62	5.33 to 12.36
4-10-73	12-5-74	25:33:00	26:18:00	109.0	-33.34	5.39 to 12.45
4-11-73	12-5-74	25:26:00	26:11:00	108.1	-33.07	5.44 to 12.53
4-12-73	12-19-74	25:17:00	26:02:00	109.0	-33.37	5.34 to 12.40
4-13-73	12-19-74	25:10:00	25:55:00	108.1	-33.09	5.37 to 12.46
4-14-73	12-22-74	25:03:00	25:48:00	107.9	-32.93	5.42 to 12.53
4-15-73	1-24-75	24:53:00	25:38:00	110.1	-33.89	5.11 to 12.12
4-16-73	1-24-75	24:47:00	25:32:00	109.2	-33.55	5.26 to 12.31
4-17-73	2-14-75	24:41:00	25:26:00	110.2	-34.01	5.32 to 12.34
4-18-73	4-28-75	24:42:00	25:27:00	115.4	-37.03	5.33 to 12.06
4-19-73	4-29-75	24:35:00	25:05:00	114.6	-36.51	5.19 to 9.73
4-20-73	4-30-75	24:29:00	24:59:00	113.7	-36.2	5.28 to 9.85
4-21-73	5-1-75	24:23:00	24:53:00	112.7	-35.59	5.35 to 9.96
4-22-73	5-27-75	24:22:00	24:52:00	114.4	-36.34	5.52 to 10.10
4-23-73	6-12-75	24:20:00	24:50:00	114.6	-36.55	5.73 to 10.30
4-24-73	6-28-75	24:18:00	24:48:00	114.9	-36.77	5.87 to 10.43
4-25-73	7-14-75	24:16:00	24:46:00	115.4	-36.99	5.96 to 10.52
4-26-73	7-30-75	24:15:00	24:45:00	115.5	-37.21	6.16 to 10.71

Table 9. Key flight events

Mark event No.	Event	Approximate time from launch, (s)
1	Liftoff (5.08 - cm motion)	0
2	Booster engine cutoff (BECO) - Atlas	139
3	Jettison Atlas booster engine	142
4	Jettison Centaur insulation panels	184
5	Sustainer engine cutoff (SECO) - Atlas	250
6	Atlas/Centaur separation	251
7	Main engine start (MES) - Centaur	261
8	Jettison nose fairing	273
9	Main engine cutoff - Centaur MECO	710[a]
10	TE 364-4 spinup rocket ignited (MECO +70 s)	780
11	Centaur/TE 364-4 separation (MECO +72 s)	782
12	Start Centaur retrothrust	782
13	TE 364-4 ignition (MECO +85 s)	795
14	TE 364-4 burnout (MECO +129 s)	839
15	TE 364-4/Pioneer G separation (MECO +229 s)	939
16	YO[b] deploy	942[c]
17	Spacecraft despin	1039
18	RTG turnon	1339

[a]MECO would be variable from 709 to 717 s.

[b]Despin counterweight.

[c]Estimated time for this event.

Table 10. NETDS Class I requirements

Class I requirement	Type of data	Stations required to provide support
T-75 min to T-5 min	Atlas telemetry (TLM) (2215.5 MHz) Centaur TLM (2205.5 MHz) TE 364-4 TLM (2550.5 MHz)	AE and CIF
Start of spacecraft countdown to T-10 min	Spacecraft TLM (2292.0 MHz)	DSS 71
T-5 min to T+5 min	Atlas TLM (2215.5 MHz)	AE/STS or CIF
T-5 min to Antigua LOS	Centaur TLM (2202.5 MHz)	AE/STS or CIF and Antigua (either TAA-3 or TAA-8)
T-5 min to YO deployment	TE364-4 TLM (2250.5 MHz)	AE/STS or CIF, Antigua, Vanguard or RIA
One-hour interval starting at initial two-way acquisition	Spacecraft data both metric and TLM (2292.0 MHz)	ACN or DSS 51
Launch to Centaur MECO + 60 s	Centaur C-band data	MIL (19.18) or Patrick (0.18), and Antigua (91.18)
MECO through YO Deployment	TE364-4 C-band data	Vanguard

Table 11. Pioneer G composite of expected coverage, metric data[a]

NETDS supporting station AOS/LOS		Expected coverage in seconds from launch			
		Window Open	Window Open +15 min	Window Open +30 min	Window Close
MILA/PAT[b]	AOS	12	12	12	12
GTK	AOS	204	206	206	206
BDA	AOS	280-282	282-284	286-288	290-292
ANT	AOS	388-390	396-398	402-404	408-410
MILA/PAT	LOS	506-508	494-496	484-486	476-478
BDA	LOS	608-623	594-615	582-598	574-590
GTK	LOS	652-658	644-648	636-642	634-640
VAN	AOS	718-720	716-718	714-716	710-712
ANT	LOS	763-773	770-780	782-795	812-820
ASC	ASO	965-973	957-965	950-955	944-948
VAN	LOS	1318-1328	1326-1330	1328-1332	1328-1334
TAN[c]	AOS	1640-1685	1645-1690	1655-1700	1665-1710

[a]Launch days April 5 through April 26.

[b]Cape Kennedy radar (1.16) will probably support the mission as a range safety radar with coverage similar to MILA and Patrick.

[c]Tananarive will be tracking Centaur vehicle, signal will be marginal.

Table 12. Pioneer G composite of expected coverage, launch vehicle telemetry data[a]

NETDS supporting station AOS/LOS		Expected coverage in seconds from launch			
		Window Open	Window Open + 15 min	Window Open +30 min	Window Close
STS/CIF	AOS	0	0	0	0
BDA	AOS	280-282	282-284	286-288	290-292
ANT	AOS	388-390	396-398	402-404	408-410
STS/CIF	LOS	501-503	489-491	479-481	471-473
BDA	LOS	526-540[b]	524-534[b]	522-532	520-528
VAN	AOS	718-720	716-718	714-716	710-712
ANT	LOS	763-773	770-780	782-795	812-820
ACN	AOS	983-1010	973-1005	965-985	958-965
VAN	LOS	1318-1328	1326-1330	1328-1332	1328-1334
ACN	LOS	1628-1648	1630-1646	1630-1648	1629-1649
TAN[c]	AOS	1675-1715	1685-1725	1700-1735	1710-1730

[a]Launch days April 5 through April 26.

[b]Bermuda will have a low elevation angle pass for each of the daily Pioneer G launch windows. Early LOS will be caused by this low elevation angle and a large BDA station mask. During the daily window open through window open plus 15 min period, additional Bermuda coverage may be obtained from 564 s to 623 s.

[c]Tananarive will be tracking Centaur vehicle.

Notes: (1) Vanguard will lose Centaur signal approximately 30 seconds after start of TE 364-4 burn.

(2) RIA will be signal limited in its coverage and is not expected to track much farther than 720 km in range. However, this should allow coverage of third stage burn, spacecraft separation, and YO deployment.

(3) VAN and ACN LOS also will be caused by signal limitations. Coverage estimates are based on a telemetry signal no greater than -10 dB.

Table 13. Pioneer G composite of expected coverage, spacecraft telemetry data[a]

NETDS Supporting Station AOS/LOS		Expected Coverage in Seconds from Launch			
		Window Open	Window Open +15 min	Window Open +30 min	Window Close
DSS 71/MIL	AOS	0	0	0	0
BDA	AOS	280-282	282-284	286-288	290-292
ANT	AOS	388-390	396-398	402-404	408-410
DSS 71/MIL	LOS	501-503	489-491	479-481	471-473
BDA	LOS	526-540[b]	524-534[b]	522-532	520-528
VAN	AOS	718-720	716-718	714-716	710-712
ANT	LOS	763-773	770-780	782-795	812-820
ACN[c]	AOS	983-1010	973-1005	965-985	958-965
VAN	LOS	1338-1382	1748>1800	>1800	>1800
DSS 51	AOS	1265-1275	1265-1275	1265-1278	1270-1280

[a]Launch day April 5 through April 26.

[b]Bermuda will have low elevation angle pass for each of the daily Pioneer G windows. Early LOS will be caused by low elevation angle and BDA station mask. During daily window open through window open plus 15 min period, additional Bermuda coverage may be obtained from 564 s to 623 s.

[c]ACN should track spacecraft signal for several hours after launch.

Note: The ARIA coverage should be somewhat signal limited, but coverage between Antigua LOS and Ascension AOS should be obtained.

Table 14. NETDS stations that may be range limited

Station	Link	Probable range where signal will be marginal, km	Remarks
RIA	TE 364-4 tlm	720	May not reacquire
VAN	TE 364-4 tlm	6600	May not reacquire
ASC	TE 364-4 tlm	1820	May not reacquire
ACN	TE 364-4 tlm	6400	May not reacquire
TAN	Centaur tlm	8000	Intermittent tracking, will depend on aspect angle after this range
ASC	TE 364-4 C-Band	9000	Same as above
TAN	Centaur C-Band	7000	TAN may have trouble acquiring because of the long range at acquisition, will depend on aspect angle

Table 15. DSN GCF/NASCOM special communications support requirements

Event	Date (Planned)	Special communications support (NASCOM standard procedures Document 2A-1 defines the various types of coverages listed below.)	Coverage periods
Launch	April 6	Special coverage	L-6h to L+4h (DSS 71 and Bldg AE)
		Special coverage	L-3h to LOS (DSS 51 and ACN)
Midcourse maneuver	L + 4D	Special surveillance full NASCOM coverage	Maneuver (M)-1 day to M+1 day M-2h to M+2h (DSSs to be provided)
Second maneuver	L + 30D	Special surveillance full NASCOM coverage	M-1 day to M+1 day M-2h to M+2h (DSSs to be provided)

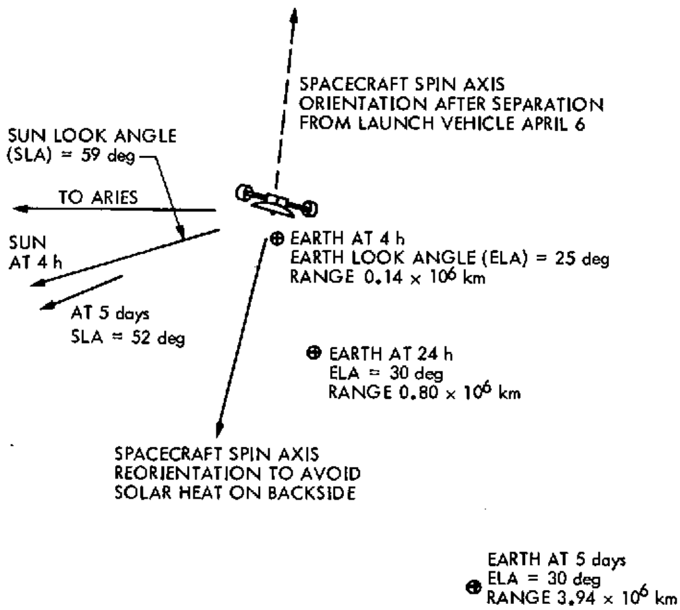


Fig. 10. Spacecraft spin axis orientation

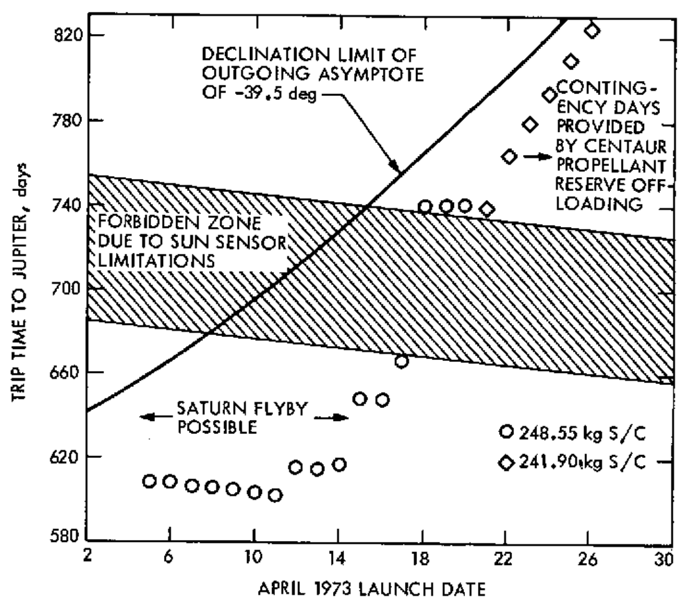


Fig. 11. Comparison of Pioneer 10 and 11 trajectories and event times

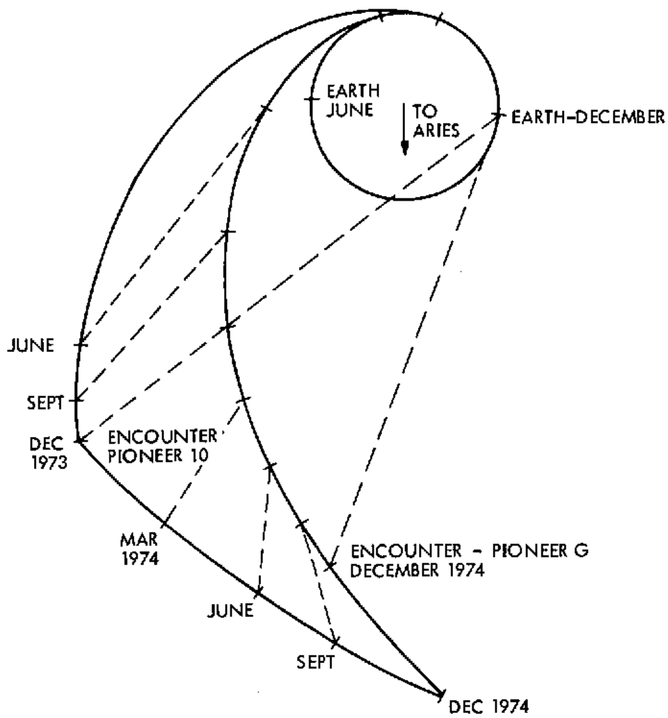


Fig. 12. Comparison of Pioneer 10 and 11 trajectories and event times

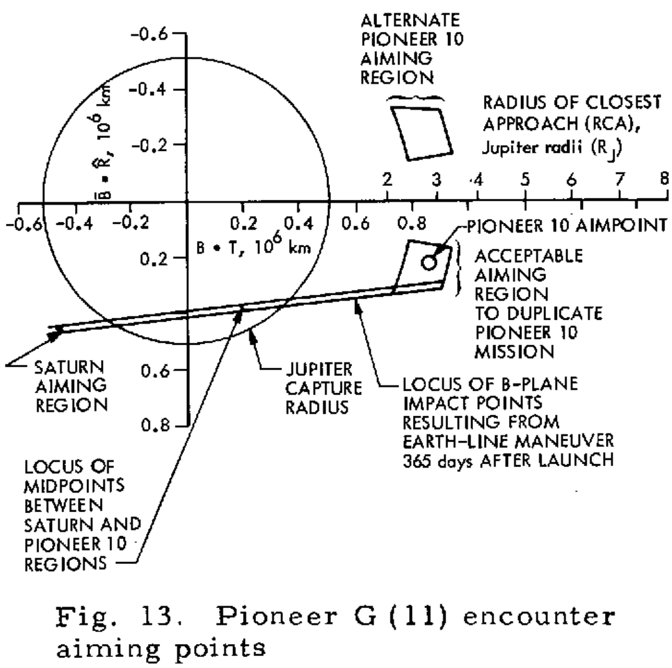


Fig. 13. Pioneer G (11) encounter aiming points

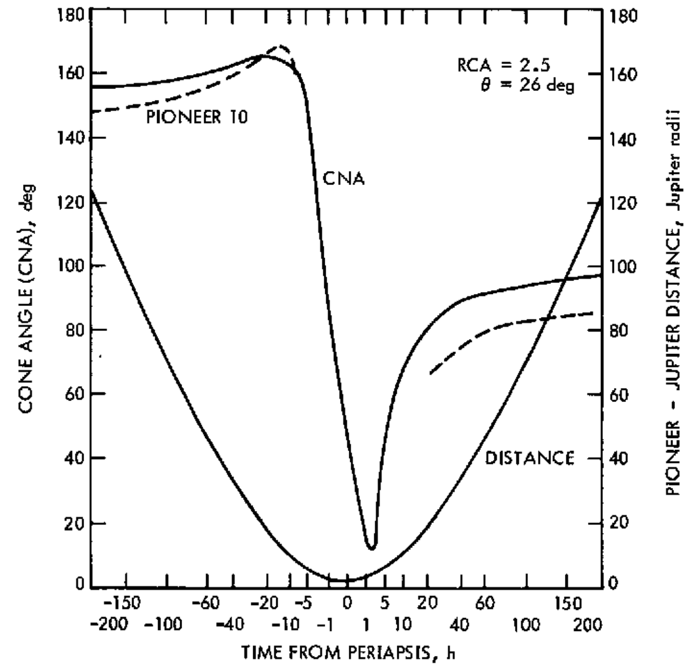


Fig. 14. Pioneer Jupiter cone angle and distance during encounter for Pioneer G typical aim point: launch date of April 18, 1973, trip time = 606 days

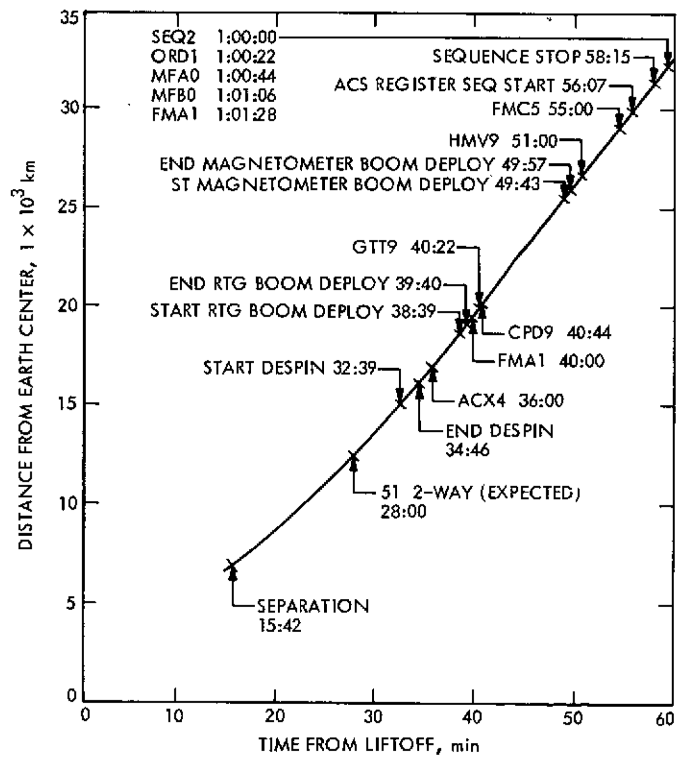


Fig. 15. Pioneer G sequence of events, first hour after launch

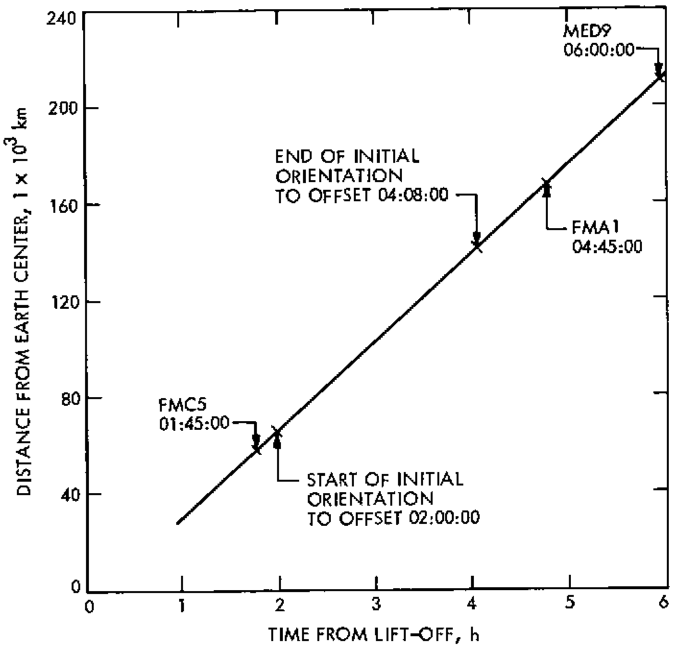


Fig. 16. Pioneer G sequence of events, from 1 to 6 hours after launch

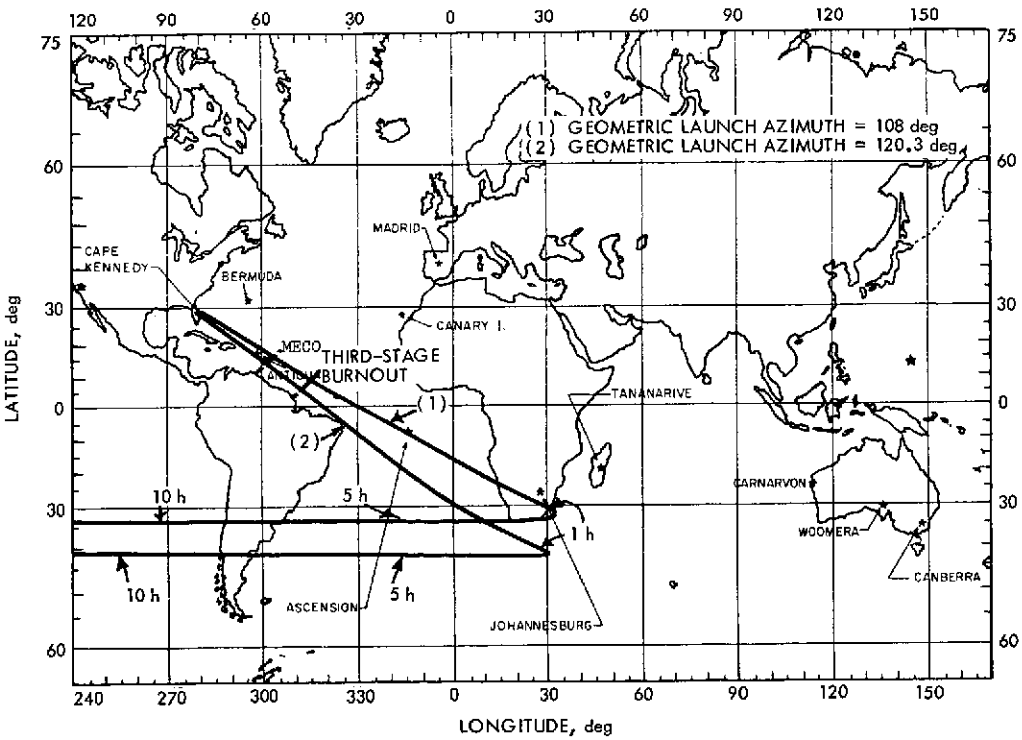


Fig. 17. Earth tracks for the nominal Pioneer G corridor

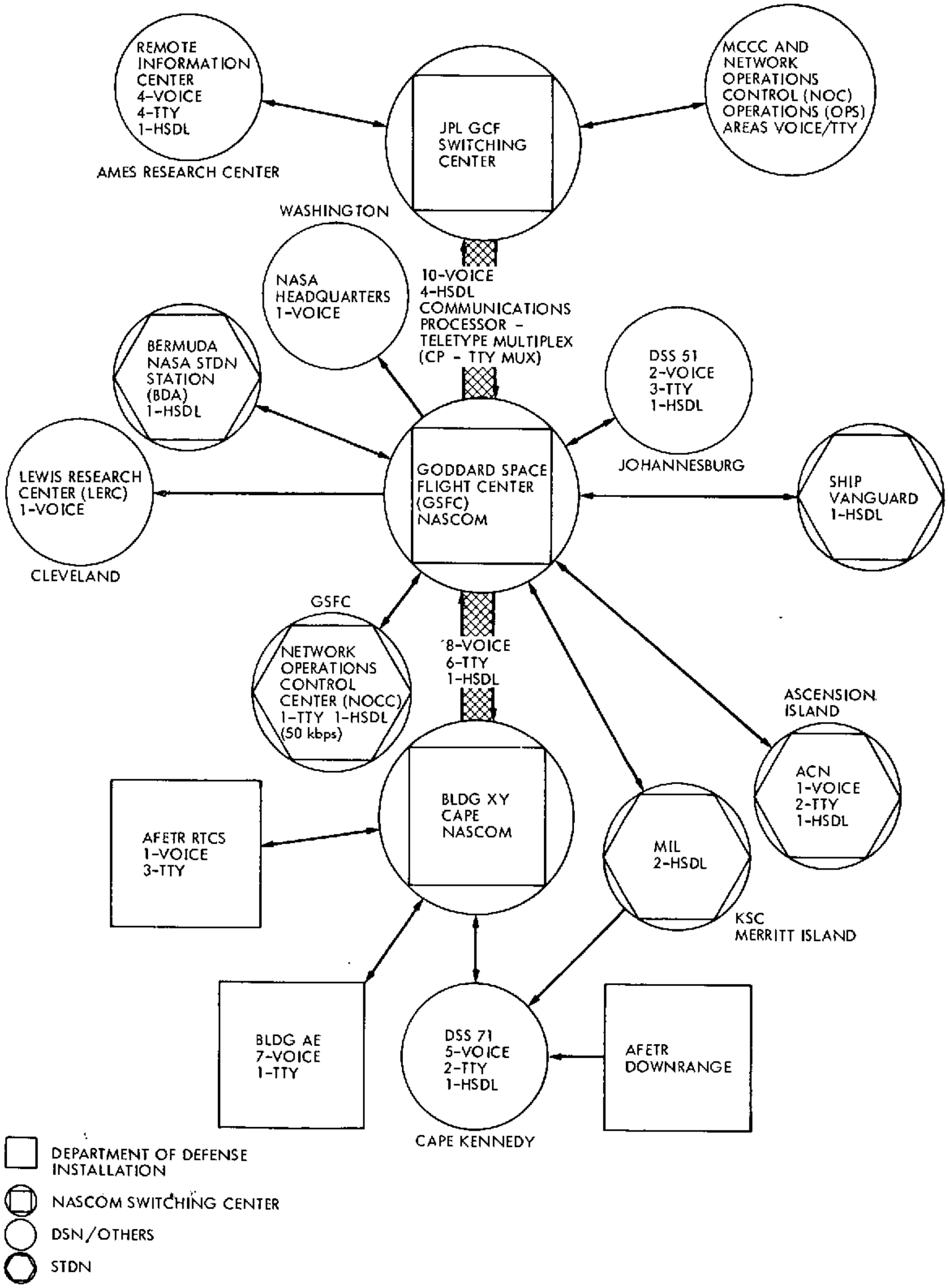
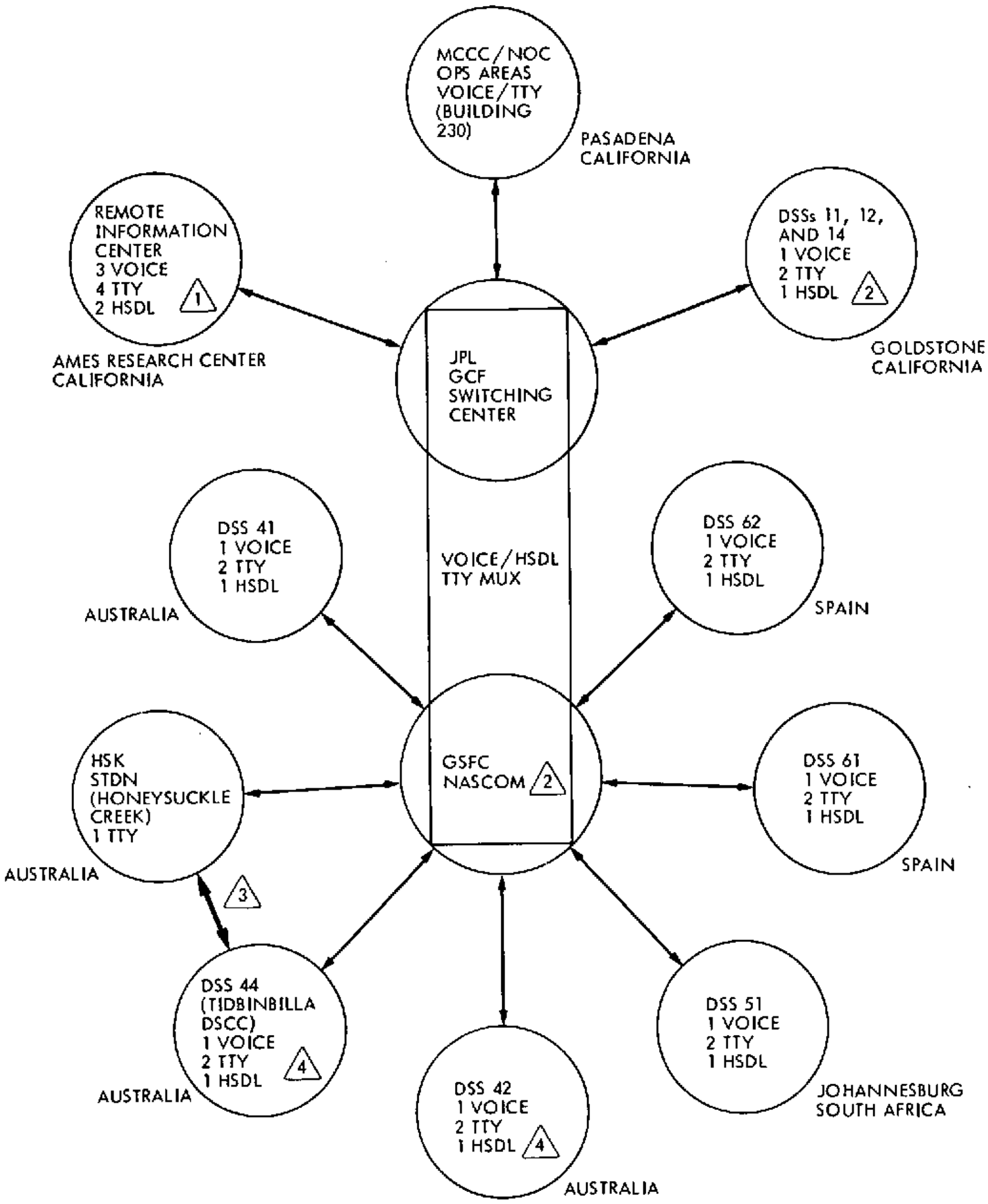


Fig. 18. DSN-NASCOM-STDN-AFETR support locations and circuit interface for Pioneer G near-Earth phase; near-Earth phase for communications support will include period from prelaunch count to L + 5h

ORIGINAL PAGE IS
OF POOR QUALITY



(1) VOICE CIRCUITS SHARED WITH PIONEER 6-9

(2) VOICE CIRCUITS FROM DSS's WILL BE CONFERENCED BY GOLDSTONE DSC 10 OR GSFC SWITCHING CENTERS, AS APPROPRIATE

(3) VOICE AND TTY INTERFACE IS VIA INTERSITE MICROWAVE SYSTEM

(4) TTY SHARED WITH DSS 42 AND DSS 43

Figure 19. Pioneer G maneuvers and cruise phase support locations and GCF-NASCOM circuit interfaces

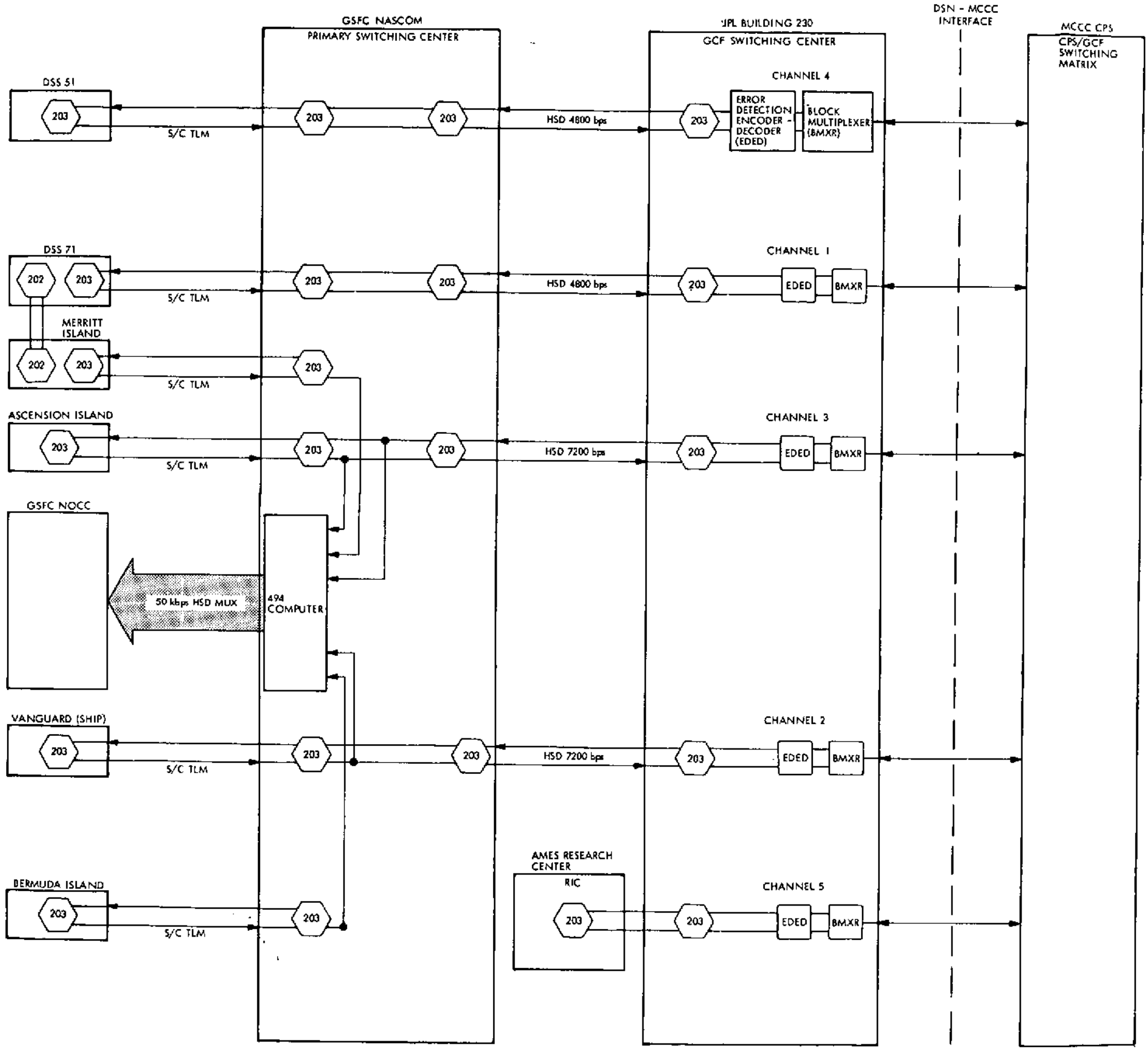


Fig. 20. JPL-NASCOM-STDN high speed data configuration and utilization plan for Pioneer G launch

ORIGINAL PAGE IS
OF POOR QUALITY

VI. PREFLIGHT TESTING

A. TEST PLAN

1. Approach

The TDS test program for the Pioneer G (11) Mission was prepared jointly by the Spacecraft System, Mission Operations System (MOS), and TDS, and was consistent with the Mission Operations Master Test Plan.

Compatibility tests were designed to demonstrate and verify compatibility between the Spacecraft System and the DSN System. Software tests were designed to demonstrate correct functioning and operational readiness of the software system. Training tests were designed to train TDS personnel in correct operation of the software and data system. Training practice provided to MOS personnel under the Mission Operations Training Plan provided training and testing of TDS personnel and configurations in addition to that provided by the TDS test plan.

TDS testing was conducted under the DSN/Spacecraft Compatibility Test Plan, the DSN Test Plan, and the TDS Near-Earth Phase Test Plan. Although the TDS began support of Mission Operations tests some months prior to launch, the support of these tests was used for additional training and testing of the TDS, and supplementary operational verification tests were scheduled to gain more experience with, and correct, operational procedures.

2. DSN/Spacecraft Compatibility Test Plan

The approach to DSN/spacecraft compatibility testing on the Pioneer G Mission was to demonstrate first a compatible RF interface between the spacecraft and a DSS telecommunications system. Next, the compatibility of the spacecraft and DSN Telemetry and Command Data Systems was to be demonstrated by the proper processing of data. The tests were conducted between the spacecraft located at TRW, Redondo Beach, and CTA 21 at JPL, Pasadena, by use of microwave link. The second phase of compatibility testing verified the design compatibility established at JPL by RF verification tests conducted at Cape Kennedy between the spacecraft and DSS 71.

3. DSN Test Plan

The objectives of the DSN Test Plan were to demonstrate: (1) the integrity and internal compatibility of the DSN Data System; (2) the correct functioning of the station Network, GCF, and MCCC configurations committed to support the mission; and (3) DSN operational readiness to support the mission. Basically, the plan consisted of three types of tests: (1) subsystem integration, (2) system integration, and (3) operational verification. The integration tests were designed to demonstrate that the engineering features of the subsystem/system were met. The tests started at the facility level with testing of the mission-dependent equipment and software, in the multimission environment. The network system level integration test followed. Upon completion of these tests, the facilities were transferred from the developing to the operational organization, and Operational Verification Tests (OVT) demonstrated the adequacy of operational procedures to conduct mission operations.

4. MOS Test Plan

TDS-supported tests were conducted by the MOS to demonstrate the capability of executing space flight operations in accordance with the Space Flight Operations Plan (SFOP). Such tests were under the direction of the Chief of Mission Operations (ARC-1), and carried out under the MOS Test Plan. All such tests were supported by the DSN Project Engineering Team, Operations Team, and Simulation Team. All tests were conducted at the MCCC with support as required from Network Control, GCF, Deep Space Stations, MSFN, and AFETR. Although outside the DSN Test Plan, these tests afforded valuable training and test experience to the TDS.

5. Prelaunch Conclusions

Test(s) and training prior to launch demonstrated:

(1) GDS capability to support two spacecraft.

(2) DSN/MCCC/MOS operational interface to be satisfactory.

(3) DSN/MCCC personnel training to be complete.

(4) No outstanding discrepancy reports that could impact launch.

B. DSN TEST SUPPORT REVIEW

1. General

By the close of January 1973, the Pioneer G spacecraft had all of the scientific instruments integrated and had passed the systems acceptance vibration and thermal vacuum tests. The spacecraft preshipment review was held at TRW on February 1 and 2, with shipment on February 15. There were no major problems for the JPL Ground Data System (GDS) or TDS during the review.

With the DSN completion of support of GDS testings in early February, the MOS testing was started February 15. It was successfully completed by the end of March as scheduled. This testing included the operational readiness tests.

Station freeze in launch configuration was ordered March 29 after final DSN configuration verification tests were satisfactorily completed.

2. MOS

All MOS testing was directed from the Pioneer Mission Support Area at JPL and interfaced directly with Pioneer Mission Operations Center (PMOC) at ARC. Successfully completed were 4 h of MOS readiness training tests, 12 h of MOS launch abort tests, 12 h of MOS S/C-DSS 71 (compatibility) tests, and 16 hours of Operational Readiness Tests (Nos. 1 and 2) during March.

The Operational Readiness Tests (ORTs) demonstrated that MOS personnel training was sufficient and that the MOS team was ready, together with all elements of the GDS, to support the mission.

With launch readiness demonstrated and verification tests successfully completed, station freeze in launch configuration took place on March 29.

The navigation team completed its scheduled testing, culminating with the two ORTs. Using the CTA 21 software released for use on the floor, 1108 Beta computer block time was scheduled for team support. With the 1108 Alpha in the same configuration it could be called upon for support should there be a Beta computer failure. Navigation software 1108 and 1108-360/75 computer interfaces were fully exercised and placed under configuration control. The team was trained and its internal and external interfaces exercised successfully to achieve a high degree of confidence in performing navigation tasks in preparation for launch and maneuver phases of the mission.

3. GDS

GDS tests demonstrated that the acceptable spacecraft-generated telemetry data could be processed in real time for mission operations use and that the GDS could simultaneously support Pioneer 10 and G telemetry, command, and tracking data flow.

During the system's integration and performance tests, the GDS demonstrated that all Pioneer G launch-essential and Pioneer 10 operational requirements could be met. During a total of 146 GDS test hours, all GDS personnel obtained sufficient training. As a part of contingency training, manual commands were transmitted to the stations.

The planned GDS test and training schedule is shown in Fig. 21.

All data flow interfaces between the stations of the near-Earth and deep space networks, the MCCC/PMSA and ARC/PMOC functioned properly.

4. PMOC

ARC's Sigma 5 computer SOLDOPS software was tested while interfacing with JPL's 360/75 for Pioneer G launch support. For direct on-site telemetry processing, Sigma 5's BUFOPS software was also used and tested. BUFOPS was interfaced with the 360/75's generated telemetry stream.

It was demonstrated that with the off-line Sigma 5 system, a backup for the prime Sigma 5, it was possible to simultaneously process Pioneer G data in the prime system and Pioneer 10 data in the backup system. In this configuration, the off-line machine could not be used for experiment data record processing, its usual function.

After launch, the third Sigma 5 was shipped from Cape Kennedy to ARC, increasing the data handling capability to two on-line and one off-line computers.

A satisfactory performance was demonstrated for the science data processing and analysis functions, which were tested on both of the currently used Sigma 5's.

The MOC facility and its personnel at ARC were thoroughly tested for launch support and reported ready.

5. MCCC

The updated Model 7 software version for the 360/75 system was placed on-line on schedule and was used in support of Pioneer G testing of the Ground Data System as well as Pioneer 10 flight operations. Approved by the MCCC facility Configuration and Control Board, the updated version gave additional capabilities to the baseline software, including the Automatic Telemetry Recall System (ATRS).

All required modifications to the mission support area at JPL were completed on time. These modifications consolidated the control of the monitoring for both the Pioneer 10 and G missions. The updated Model 7 software enhanced the 360/75 data system's support of the combined flight operations.

The latest mission data record guidelines were included in the updated version of the Pioneer 10 and G mission support plan. The MCCC planned to use the ATRS to fill recoverable data stream gaps and interface with the on-site computers. The DSN would provide ATRS support on a "best effort" basis, and any ATRS malfunction was backed up by manual or 100% digital Original Data Record (ODR) recall. ATRS problems continued into April and minor errors prevented completion of telemetry recalls in the 1-h post-pass time provided for the purpose. A decision was made to use the system as delivered and employ work-arounds with a corrected version of the program produced after spacecraft midcourse maneuver corrections.

6. Station Prelaunch Participation

DSSs 11, 12, 14, 42, and 51 conducted simulation tests in preparation for the Pioneer G mission during December 1972.

During January 1973, two series of DSN Operational Verification Tests (OVT) were conducted with satisfactory results, although some hardware/ software and procedural problems were encountered. The first OVT series on January 12 included DSSs 14, 51, 71, 12, and 42. The second series on January 16, 18, and 19 included DSSs 12, 14, 51, and 71.

A Performance Demonstration Test on January 19 and 20 proved the readiness of DSSs 12, 71, 14, 42, and 51 to support all subsequent Pioneer G GDS and MOS tests. Also in January, DSSs 42, 51, 12, and 71 participated in GDS Integration Tests.

DSS 11 was removed from a Pioneer G support role when an extensive update program was initiated during January. At the end of the month, an S/X-band implementation eliminated DSS 14 support until completion of the work on March 26.

7. Tracking Prelaunch Support

Network Operations Analysis/Tracking support of prelaunch activities included the following items:

a. January

(1) Open-window, midwindow, close-window and abort (no third-stage burn) predicts cases were generated for DSS 51 and Ascension MSFN (ACN).

(2) Open window and abort predicts were generated for use in preparing simulated data for network testing purposes.

(3) Graphs of two-way doppler rate, angles rates, and stereos for open-window, midwindow, close-window, and abort cases for DSS 51 and ACN were prepared for the initial acquisition study.

b. February

(1) Numerous predicts were generated to provide the simulation center with data used to create simulated tracking data.

(2) Support was given to several launch and midcourse maneuver tests; several predicts sets were generated during each test.

c. March

(1) Numerous predicts were generated to cover nominal launch situations, and no third-stage burn trajectories.

(2) Procedures used in initial spacecraft acquisition at DSS 51 were completed.

(3) Procedures were completed to satisfy data requirements of the Pioneer G Navigation team.

(4) Support was given to operational readiness tests (both launch tests and midcourse maneuver tests).

C. NEAR-EARTH TEST REPORTING

1. Testing Levels

There were three levels of testing established: (1) subsystem prerequisite tests, (2) systems integration and verification tests, and (3) combined systems and performance tests. With the summarization of systems integration and verification tests and the combined systems and performance test, this section presents the near-Earth TDS performance in the MOS training exercises.

The TDS Near-Earth Test Plan (Ref. 6) was used as the criterion for developing test procedures and schedules for the Pioneer G Mission.

2. System Integration and Verification Tests

Individual test objectives are reported here.

a. Telemetry

(1) Simulation Center (SIMCEN)/DSS 71/MCCC software verification: to verify that simulated data from the DSN

Simulation Center (SIMCEN), which were reformatted into HSD blocks by DSS 71, were compatible with the MCCC 360/75 spacecraft data input program.

(2) RF readiness demonstration: to verify all launch area and AFETR RF loops and data transmission circuits.

(3) Live spacecraft data verification: to verify the NETDS software against the live spacecraft data.

(4) Communications loop back to DSS 71: to evaluate the data communications circuits between DSS 71 and the AFETR receiving sites, which was accomplished by typical terminal communications modulator/demodulators (modem) at each site back-to-back and observing DSS 71 simulated data as it is looped back to DSS 71 from each receiving site.

(5) SIMCEN/STDN/MCCC compatibility: to demonstrate that Goddard Space Flight Center (GSFC) 642B computer software was compatible with SIMCEN and MCCC software. This was accomplished by tying in 642B computer output (simulated data from the SIMCEN) back-to-back to the computer input (spacecraft data) and observing the simulated data as they were looped back from GSFC.

(6) STDN computer/communication demonstration: to verify the HSD format and 642B computer program compatibility at each STDN receiving site. This can be accomplished by tying the computer output (simulated data) back-to-back to the computer input (spacecraft data), and observing the simulated data as they are looped back to GSFC from each receiving site.

b. <u>Tracking</u>

(1) S-band metric data and acquisition predicts test: to verify compatibility of DSN and GSFC formats with the AFETR RTCS, and to evaluate processing accuracy and capability

of the RTCS. Also, to verify format and content of RTCS real-time predicts that were planned for the Pioneer G Mission.

(2) Vanguard C-band test: to test the C-band metric data flow interface between VAN and the RTCS, verifying that the RCTS could accept and process VAN data to the accuracy required.

(3) Mapping to Jupiter encounter demonstration: to determine the accuracy of the RTCS mapping program output parameters as compared to MCCC mapping program output parameters.

3. Combined Systems Performance Test

The objective was to evaluate the over-all data receiving/data transmission system in preparation for the first Operational Readiness Test (ORT). This test would demonstrate the near-Earth launch configuration with all systems operating simultaneously.

The test was performed on March 15, 1973. T-0 was 1700 GMT. A launch on April 6 at 0211:00 GMT was simulated with a geometric launch azimuth of 111.45 deg.

The participating stations were:

STDN	AFETR	PROJECT
BDA	RTCS	Navigation (NAV) Team
VAN	Antigua (telemetry, only)	MCCC
ACN	Ascension (telemetry, only)	SIM CENTER
TAN	TEL-4 (AFETR mainland telemetry station)	
Network Operations Control Center (NOCC)	DSN	
Network Test and Training Facility (NTTF) (Standby)	DSS 71	
Goddard Real-Time System (GRTS)	DSN Operations Control	

KSC

AE TLM Laboratory

AE Mission Direction Center (MDC)

The test was satisfactorily completed. The main problem encountered was the receiving and processing of SIMCEN data at the STDN sites. Use of the improper destination identification (ID) was the offender.

4. MOS Training Exercises

Two simulated metric data packages were prepared by the AFETR/ RTCS for use by the MOS in tests at the MCCC. One package consisted of data for a nominal launch and the other for a launch emergency abort test.

In addition to this, the NETDS participated in two ORTs which are reported here.

a. Pioneer G ORT 1, March 23. At 1 minus 0 1953 GMT March 23, a launch on April 16 at 0053:00 GMT with a geometric launch azimuth of 109.48 deg was simulated. The test was successfully completed.

The participating stations were:

STDN	AFETR	KSC
BDA	RTCS	CIF
VAN	Antigua	AE TLM LAB
ACN	Ascension	AE MDC
TAN	TEL-4	
NOCC		
NTTF (Standby)	DSN	
GRTS	DSS 71	
	DSS 51	

b. Pioneer G ORT 2, March 30. At T minus 0 0211 GMT, March 30, launch on April 6 at 0211 GMT with a geometric launch azimuth of 111.45 deg was simulated. The test was successfully completed.

The participating stations were:

STDN	AFETR	KSC
MIL	RTCS	CIF
BDA	Antigua	AE TLM LAB
VAN (at sea)	Ascension	AE MDC
ACN	TEL-4	
Ground Canary Island (Spain) (CY1)		
TAN	DSN	
NOCC	DSS 71	
NTTF (Standby)	DSS 51	
GRTS		

5. Ground Communications Facility

There was no special testing of the Ground Communications for Pioneer 11 Mission since operations for Pioneer 10 Mission were in effect and were successful.

D. LAUNCH VEHICLE AND SPACECRAFT TESTING

Significant launch vehicle and spacecraft prelaunch milestones are presented in Table 16.

1. Launch Vehicle Summary

a. Terminal Countdown Demonstration (TCD), March 2. The test began as scheduled at T-585 min at 0705 (GMT) with a scheduled T=0 at 1800. To simulate an actual launch configuration, two planned holds were used at T-100 min for 1 h and T-10 min for 10 min.

The test progressed in accordance with the procedure to T-14 s where the count was held while some special boiloff valve tests were conducted. At the conclusion of the boiloff valve tests, a special plus count in a "safe" configuration was to have been performed while the vehicle was detanked. The plus count was scrubbed, however, in lieu of troubleshooting the guidance system, which experienced a time check out of tolerance condition (OTC) during the test as well as a V gyro OTC. Other anomalies that occurred were:

(1) The manual valve from the LO_2 storage tank to the LO_2 vaporizer leaked. The leak was repaired following the test.

(2) The He bottle charge valve in the positive continuous ullage control (PCUC) ground-support equipment (GSE) was leaking through in the Centaur pneumatic system. The situation remains but has been relieved by a change in operational technique. The valve was changed out following launch.

(3) Green phone communications from the blockhouse to water pump station number 4 were interrupted for a short time. The situation was corrected and communications restored.

(4) A procedural error allowed the Atlas engine arm switch to remain in the arm position during the hold and thus prevent the start tanks from being pressurized. The error was detected without undue delay and the tanks were pressurized.

(5) A 480-V feeder station was inadvertently "dropped out" while trying for a blockhouse configuration. The feeder station was then configured correctly.

(6) During the Centaur end-to-end dynamic test in the flight command system, vector F1V had an unexplainable glitch. This anomaly was determined to be a software initialization problem.

(7) During the minus count, RF control capability to the Centaur digital computer unit (DCU) was lost when uplink was lost from the remote digital interface equipment (RDIE) because of the power dropout (refer to item (5)).

(8) During the propellant utilization (PU) functional portion of the test, a C1 positive slew on the servo actuator was in an OTC. However, telemetry indicated there was no anomaly.

(9) During the range safety control (RSC) test, the Range failed to send MECO on the initial try.

b. Flight Events Demonstration (FED) Test Number 1, March 6. The test began as scheduled at T-75 min, at 1445 GMT with a scheduled T=0 at 1600 GMT. The test was conducted without the RSC receivers turned on because of a Range schedule conflict. The count proceeded normally until T-8 s when the count was stopped because the insulation panel vent door did not show open. The count was recycled to T-5 min and resumed when it was learned that the purge bottle was at too low a pressure. The count proceeded normally through T=0 and culminated in a successful test.

The only plus time anomaly resulted when the insulation panel quad II jettison panel indication occurred approximately 20 s late. This was isolated to a cable problem within the gantry test rack.

c. FED Test Number 2, March 23. The test was successfully conducted on AC-30, the third stage, and the Pioneer spacecraft. The test began as scheduled at T-150 min, at 1330 GMT, and culminated with a T=0 at the planned time of 1600 GMT. During the test the following anomalies were noted:

(1) The spacecraft was late in powering up because of a loss of air conditioning in Hangar AO. The spacecraft was powered up after air conditioning was restored.

(2) Flight control experienced OTCs in the (+) yaw and roll gains during the early part of the test. However, indications were that these OTCs were due to software.

d. Composite Electrical Readiness Test (CERT), March 29. The test was successfully conducted on AC-30, the third stage, and the Pioneer spacecraft. The test began as scheduled at 1245 GMT at T-75 min with a planned T=0 at 1400 GMT. The count proceeded normally until T-60 s when the count was stopped because the data reduction equipment, discrete recorder and monitor (DRAM), in Building AE was in a nonsupport mode. Approximately 5 min later, the DRAM was operating properly and the count was resumed culminating in a satisfactory T=0 at 1409 GMT. All systems performed satisfactorily.

e. Flight (F)-3 Day Activities, April 2. Normal F-3 day ordnance mechanical installation was completed. The loop resistance checks resulted in minor discrepancies, which were waivered. The mechanical and electrical systems readiness continued with vehicle close out and securing. The trailing wire umbilical modification was still in work and calibration of this system end-to-end was begun. The terminal board rechecks of the power control unit (PCU) systems were completed.

f. F-2 Day Activities, April 3. Tanking of H_2O_2 was completed early in the morning and then post tanking and leak checks were performed. Rocket propellant 1 (RP1) was then again tanked and the system was leak checked and inspected with no significant anomalies. Also, a valve angle check was performed on Atlas propellant utilization (PU) MS110 while modification work continued on the 106.68-cm rise umbilical.

g. F-1 Day Activities, April 4. Normal F-1 day activity progressed in accordance with the procedure until the ordnance installation task. This task scheduled to be complete at 2000 GMT on April 4 was not completed until 0200 GMT on April 5 because of pad clearance for lightning. The spacecraft accomplished some work in parallel with the serial ordnance tasks; however, the RTG installation was delayed. The 106.68-cm rise installation of safety wire to support the cable and aerospace sealant to resist inadvertant disconnect prior to 106.68-cm motion was accomplished. The Atlas RSC panel meters drew 4 mA constant current. This reduced the lift of the Atlas RSC batteries by 0.16 A-h by liftoff. This left enough margin for the first two launch attempts.

h. Launch, April 5. The range countdown began at the scheduled time of 1926 GMT and continued smoothly in accordance with procedure throughout all scheduled holds and culminated in a successful liftoff at 0211:00.117 April 6 (GMT).

2. Spacecraft Activities Prior to Launch

a. Spacecraft Integrated Systems Test, March 22. A successful spacecraft integrated systems test was conducted.

b. FED Test, March 23. The spacecraft participated in this test without any anomalies.

c. CERT, March 29. No spacecraft problems were encountered during this test.

d. Radio Frequency Interference Test, March 20. The spacecraft participated in this test without incident.

e. F-3 Day Activities, April 2. Task 1 (electrical ground support equipment preparations and spacecraft instrument checks) of the spacecraft countdown was conducted.

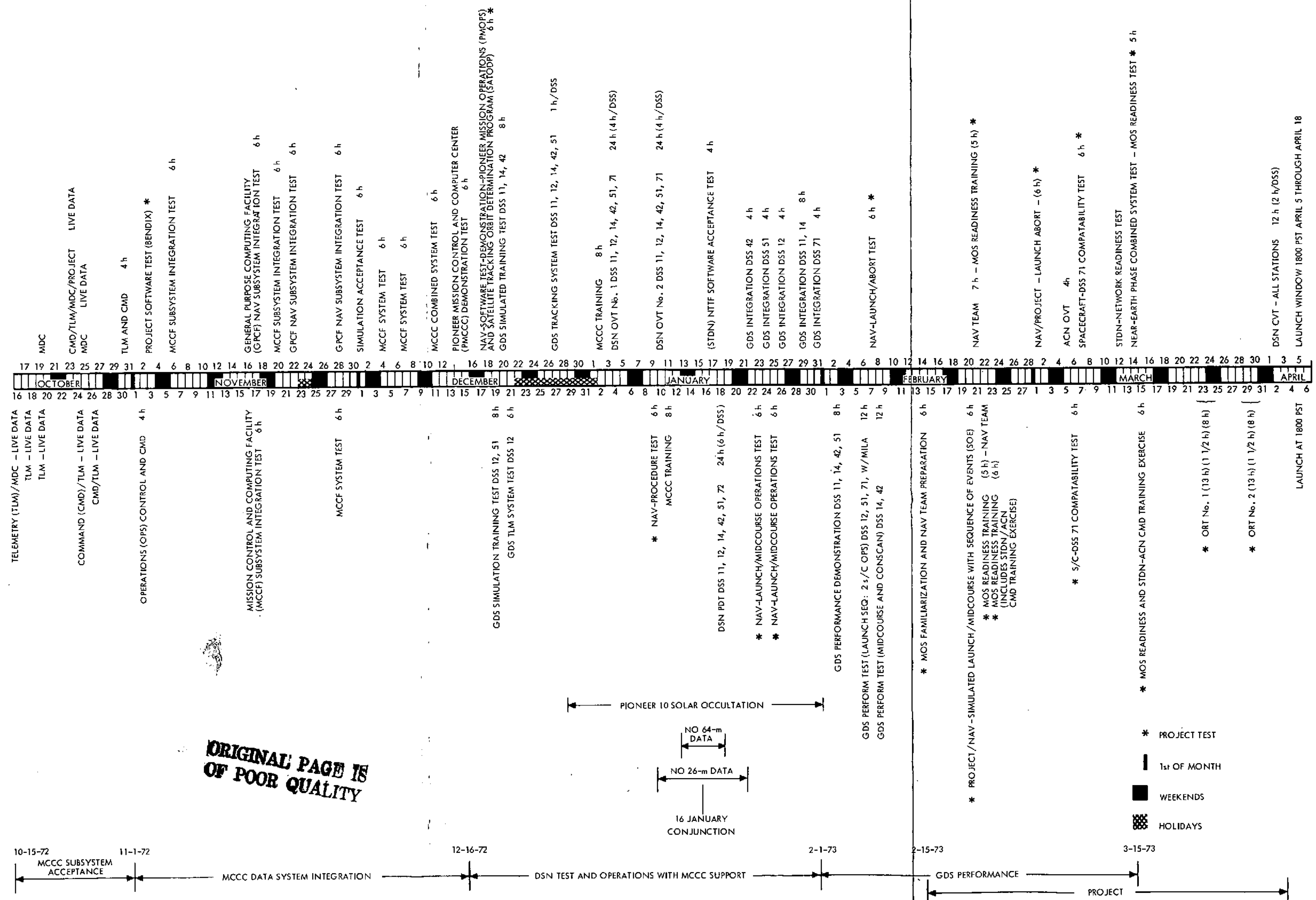
f. F-2 Day Activities, April 3. Section 1 of Task II (RTG installation preparations) was conducted.

g. F-1 Day Activities, April 2. Task II (RTG installation) was begun 4.5 h late because of poor weather conditions, which necessitated closing the pad. During the installation, one load bank, used to precondition each RTG pair, failed. Thus, each pair had to be conditioned serially. Efforts were made to parallel some of the preconditioning tasks with actual installation, and no additional time was lost.

h. Launch, April 5. RTG installation was finished at 0730 GMT on April 5 at which time Task III (spacecraft/instrument final checks) was started. This task was completed at 1300 GMT. Task IV (spacecraft finaling) was then started and was running about 1 h late. The spacecraft stood by during the vehicle closeout tasks. Task V of the countdown was picked up at T-335 min and proceeded nominally through launch.

Table 16. Launch vehicle and spacecraft prelaunch milestones

Event	Location	Date
Atlas arrived at AFETR	Hangar J	1-4-73
Centaur arrived at AFETR	Hangar J	1-4-73
Atlas erected	Complex 36B	1-9-73
Centaur erected	Complex 36B	1-10-73
Spacecraft arrived at AFETR	Building A0	2-15-73
Spacecraft performance checks conducted	Building A0	2-19 through 3-13-73
Terminal Countdown Demonstration	Complex 36B	3-1-73
Flight Events Demonstration No. 1	Complex 36B	3-6-73
Mate third stage to Ground Transport Vehicle (GTV)	ESA 60A	3-12-73
Transport spacecraft to ESA 60A (Propellant Loading Building)	ESA 60A	3-14-73
Hydrazine loading	ESA 60A	3-16-73
TRW spacecraft weighing and final inspection	ESA 60A	3-17-73
Mate spacecraft to third stage	ESA 60A	3-18-73
Remove spacecraft red tags and encapsulate	ESA 60A	3-19-73
Transport spacecraft to Complex 36B and mate to Centaur	Complex 36B	3-20-73
Mate Pioneer F to Centaur	Complex 36B	3-21-73
Spacecraft Integrated Systems Test	Complex 36B	3-22-73
Flight Events Demonstration No. 2	Complex 36B	3-23-73
Spacecraft and DSN final interface check	Complex 36B	3-28-73
Composite Electrical Readiness Test	Complex 36B	3-29-73
Radio Frequency Interference Test	Complex 36B	3-30-73
F-3, 2, and 1 day activities	Complex 36B	4-2 through 4-4-73
Launch readiness	Complex 36B	4-5-73



ORIGINAL PAGE IS OF POOR QUALITY

FOLDOUT FRAME

Fig. 21. Planned Pioneer G Ground Data System Test and Training Schedule

FOLDOUT FRAME

VII. TDS SUPPORT AND SUPPORT EVALUATION

A. GENERAL

The DSN 26-m-diam antenna network and 64-m-diam antenna station, DSS 14 at Goldstone, successfully tracked, maneuvered, and acquired data from, and sent commands to Pioneer 11 spacecraft from launch through April 30, 1973, the close of this report. The spacecraft was approximately 22.1 million km from Earth, traveling at 8.7 km/s to Earth, at the end of April.

By the close of this report, five DSN stations had expended a total of 6,667 man hours and 893 station hours with 77 tracks in support of the spacecraft flight. In addition, DSS 71 expended 70 man hours and 10 station hours supporting countdown and launch, and another 105 man hours and 15 station hours on final tasks before countdown. The Ascension Island Station (STDN) supported 4 tracks of the total of 81 tracks for the month over a total of 16 h and 43 min of the overall total of 617 h and 4 min tracking support by all stations during April. The 64-m-diam antenna station support was only 7 h and 31 min.

The support, Passes 1 through 25, for individual DSN stations was:

DSS	Total passes	Man hours	Station hours
11	9	426.5	83.5
12	16	861	172.5
14	2	175	18
42	25	1594.5	269
51	25	3620	350

B. LAUNCH

1. Launch Vehicle and Spacecraft Countdown

The launch vehicle countdown for the launch of Pioneer 11 was initiated on April 5, 1973, approximately 60 min later than planned because of adverse weather conditions that delayed the completion of the F-1 day tasks. This 60-min delay was made up by the start of the Range countdown at T-335 min at 1926 (GMT).* The opening of the 45-min window was at 0211 on April 6. The Atlas Centaur was to be launched at 108 deg and yawed to a geometric launch azimuth of 111.45 deg.

Weather conditions were excellent for this countdown. High altitude wind shear data remained well within limits throughout.

The launch vehicle countdown proceeded satisfactorily without any unplanned holds. The normal built-in holds of 60 min at T-100 min and 10 min at T-10 min were observed.

The spacecraft countdown proceeded without incidents.

2. Near-Earth TDS Countdown

The near-Earth TDS count progressed satisfactorily until approximately T-77 min when the range instrumentation aircraft (RIA) reported the antenna could not be brought out of the stowed position. As they worked on this problem, RIA personnel performed data link checkouts through the LES-6 satellite to Grand Bahama Island (GBI) and through to the Cape. These checks were hampered by poor signal margins from the LES-6. Subsequently, the RIA's antenna was released adequately enough so that they were able to provide support.

The 3600 computers at the RTCS experienced some problems in the later portion of the count (the last 30 min), first the A computer was down and when it was declared operational, the B computer went down. Both computers were operationally ready by 0154 GMT.

The Vanguard experienced problems with the Launch Trajectory Data System (LTDS) checkout that would have affected acquisition if the flight was not nominal. However, Vanguard personnel indicated they could support it.

3. Lift Off

Lift off occurred at 0211:00.117.

*All times are GMT.

C. NEAR-EARTH

1. Flight Events

Table 17 sets forth the launch vehicle flight events. The Vanguard ship, in addition, provided the following third-stage burnout parameters:

Time:	0226:36
Inertial Path Angle:	13.8 deg
Inertial Velocity:	14.3 km/s
Altitude:	472 km

Figure 22 shows the test support position (TSP) of the Vanguard and the RIA.

2. C-Band Metric Support

Figure 23 presents the actual coverage provided by the near-Earth TDS of the C-band beacons. The intervals of mandatory coverage for the Centaur and TE 364-4 are indicated.

All stations reported good track with the exception of Tananarive, which had intermittent track from approximately 0241 to LOS. The station attributed this to a bad aspect angle.

The loss of 72 s of third-stage coverage during the mandatory interval is discussed in Section VII-D-3.

3. Centaur Telemetry Support

Figure 24 presents the actual Centaur telemetry data support provided by the near-Earth TDS. All stations supported satisfactorily fulfilling the Class I support. The RIA had early LOS because the antenna had reached its lower limit.

Third-stage Thiokol TE 364-4 telemetry data coverage is shown by Figure 25.

4. Spacecraft Telemetry Support

After T-10 min (Launch (L)-20M) there was no Class I requirement for spacecraft data placed on the near-Earth TDS. Figure 26 shows the support provided by the near-Earth TDS for the Class II interval.

All stations supported satisfactorily with the exception of Antigua, which had a 3-min drop out of data as shown in Fig. 26.

5. RTCS Computations

The RTCS computed seven sets of orbital elements for the Pioneer G mission. Two sets of orbital elements were computed on the Centaur preretro orbit using Antigua data. One set of orbital elements was computed on the Centaur postretro orbit using Tananarive data. Two additional sets of orbital elements were calculated by the RTCS on the transfer orbit. Vanguard and Ascension C-band data were used for these solutions. The final two solutions were on the spacecraft orbit and were calculated from DSS 51 using two different programs, "Retran" and "Playmate".

A summary of the RTCS computed orbital elements is provided in Table 18.

The RTCS also mapped the Vanguard, Ascension, and DSS 51 solutions to the Jupiter B-plane (Fig. 27). A summary of the B-plane parameters is given in Table 19.

The RTCS also computed and transmitted nominal predicts in the minus count for Ascension (STDN) and Johannesburg (DSS 51), and two real time sets to these stations at L+32 min and L+170 min in the plus count.

6. Real Time Spacecraft Telemetry Transmission

DSS 71 processed, in real time, spacecraft telemetry for transmission to the MCCC as follows:

Time	Source
L-15 m to L+341 s	Merritt Island USB
L+341 s to 793 s	Antigua

The Antigua data had an 186-s dropout ending at L+790 s. There were other dropouts of up to 16 s in Antigua data, but the automatic switch unit (ASU) switched back to MIL data. There were no data from the RIA.

Telemetry data were processed from the near-Earth TDS in real time at the MCCC as follows:

Time	Source
L-15M to L+11M	DSS 71 (MIL and Antigua)
L+11M to L+18M	Vanguard
L+18M to L+22M	Ascension USB
L+22M to ______	DSS 51 (station continued support of S/C as a DSN station)

D. NEAR-EARTH PERFORMANCE EVALUATION

1. General

The nominal flight of Pioneer 11 during the near-Earth phase did not tax the system so that much of the data recovered, although useful, did not provide a good measure of the performance of the near-Earth systems.

The launch vehicle and spacecraft telemetry data recovered were such that if one site's data were not too useful, another site usually had data for the same interval.

The orbital computations made by the RTCS were never rated better than good; however, when mapped to the planet the results were excellent.

Definitions used for the quality of estimates were:

Excellent:	Residuals on this data are about as small as can be obtained from this source. The input data appears valid in all respects. No unexplained inconsistencies in data.
Good:	Same as above except residuals are somewhat larger.

Fair:	Orbit solution obtained, but residuals are higher than normal or input data noisy and/or small number of data points available, thus reducing confidence in solution.
Poor:	High values in residuals, and/or unexplained inconsistencies in data.

2. Performance of Systems

a. Testing. In comparison with the problems experienced in preparation for the launch of Pioneer 10, testing prior to the launch of Pioneer 11 was more successful. This, of course, can be attributed to a better familiarity with the system as a result of supporting Pioneer 10.

b. Tracking. The Class I requirement for the tracking of the Centaur C-band was met. The Class I requirement for TE 364 C-band track was not supported entirely because of an acquisition problem (the nominal interrange vectors were incorrectly flagged as in-flight data) aboard the Vanguard resulting in a loss of approximately 72 s of data at the beginning of the required interval. Subsequent data from the ship were used to compute a solution for orbital elements that was considered fair.

The 0.18 radar located at Patrick AFB, experiencing phase front shifts, lost autotrack for approximately 242 s during its track of the TE 364 (Class II requirement); the largest interval being 160 s of skin track.

Tananarive had only 7 min of valid autotrack of the Centaur throughout a 32-min pass (Class II requirement) because of a lobing beacon and bad aspect angle. The data, however, were used to provide a good solution of the Centaur postretro orbit.

The 12.16 radar met the commitment of TE 364 track (Class II requirement) with periods during which it went out of autotrack. These periods were subsequent to the committed interval. The data, although rough, provided a fair solution of third-stage orbital elements.

c. Telemetry. The Class I intervals of support of the Centaur and TE 364 telemetry links were met by the near-Earth TDS.

Antigua had a 3-min dropout of spacecraft telemetry data because of a loss of lock in the phase-shift keying (PSK) demodulator at the station.

Telemetry data recovery by the RIA was hampered by an antenna system malfunction at T+810 s causing the antenna to lose track and move to the lower limit. The operator was unable to control the antenna by either joy stick or hand wheel control. Eclipse of the LES-6 satellite prevented real time relay of the data from the aircraft through GBI to TEL 4 (AFETR main island telemetry station).

E. DEEP SPACE PHASE

1. DSN Sequence and Midcourse Maneuvers

a. Acquisition. DSS 51, the prime station acquisition of the S-band downlink signal (Ascension Island STDN was backup), acquired spacecraft telemetry signal 20 min after launch. The two-way command was made available for Mission Operations 3 min later, giving the capability to transmit commands 5 min ahead of set requirements. By the end of spacecraft signal visibility from DSS 51, the Ascension station bridged a view gap between South Africa and DSS 12 at Goldstone. To assure a continuous two-way contact with the spacecraft and its instruments, DSS 12 took over support by the end of the Goldstone pass. Using DSS 11, 43, and 62, the DSN provided simultaneous two-way support for Pioneer 10.

b. Spacecraft Sequence. The initial spacecraft sequence, deployment of the two booms supporting the RTG packages, occurred at 39 min after launch. Although one boom failed to fully deploy at this time, it was deployed fully during a subsequent maneuver to move the instruments into the shade of the high-gain antenna dish. Analysis indicated all was well with the spacecraft so the initial turn-around sequence was continued. Course orientation was obtained by 1400 on April 6. The spacecraft was left at approximately 30 deg from Earth-pointing to continue to shade the instruments from the Sun.

c. Midcourse Maneuvers. The first midcourse maneuver started with calibrations from DSS 51 on April10. The spacecraft was brought to Earth-pointing and a medium high-gain Conscan was done along with thruster calibrations. A delta V of 38 m/s started at 1150 (GMT) on April 11 with DSS 12 and 14 tracking. Final offset of 27 deg Earth-look angle was completed by 1500. Initial turnon of the Asteroid Meteoroid Detector and the Imaging Photo Polarimeter followed.

A second midcourse maneuver was supported on April 26 by DSS 42. The expected delta V of 1/2 m/s per second was obtained and the spin rate adjusted.

A precession maneuver on April 14 left the Earth-look angle at 20 deg allowing a higher telemetry bit rate.

2. Telemetry

a. Activity and Trend Analysis. Telemetry activity for Pioneer 11 was nominal during April; no telemetry trends were observed. The telemetry bit rate was 128 bps through 2048 bps.

b. Engineering Signal-to-Noise Ratio. The data plotted contain 72 signal-to-noise-ratio (SNR) readings that were found to have an arithmetic mean of 0. 3 dB, and a standard deviation of 0. 6 dB. Of these observations, 75% were less than 1. 0 dB of predicted values, and 29% were less than 0. 3 dB of the predicted values. The most often observed value was between 0. 3 and 0. 4 dB.

c. Downlink Signal Level. The data plotted contain 72 readings of downlink signal levels that were found to have an arithmetic mean of 0. 9 dB, a variance of 0. 7 dB, and a standard deviation of 0. 8 dB. Of these observations, 72% were less than 1. 0 dB of predicted values, and 22% were less than 0. 3 dB from predicted values. The most often observed value was between 0. 8 and 0. 9 dB, and 0. 9 and 1. 0 dB, equally. The average downlink signal dBm was -150. 1 dBm.

3. Command

Command activity in support of Pioneer 11 during April totaled 1,536 commands transmitted to the spacecraft. Table 20 is a summary of command activity. Table 21 shows Telemetry and Command Processor (TCP) failures affecting command with reasons and downtimes. Percent down, including 360, HSD, and station failures, is given in Table 22. Mean time between failure was: GCF, 40.9 h; station, 34.4 h; and 360 + station, 23.42 h.

4. Monitor

Monitor System support of 78 passes during April was maintained at an extremely high level for all Monitor reporting parameters. A total of 5 Digital Instrumentation Subsystem (DIS) outages was reported, and the total DIS downtime was 2.0 h. Percentage of over-all DIS support was 99.7%. Meantime between failures was an unusually high 128.1 h.

5. Tracking

a. Significant Support. Generally, all predicts sets, project tape deliveries, and acquisition instructions were both timely and accurate for Pioneer 11 launch. Support during April consisted of 81 tracks: DSS 11, 9 tracks; DSS 12, 16 tracks; DSS 14, 2 tracks; DSS 42, 25 tracks; DSS 51, 25 tracks; and DSS 75 (ACN), 4 tracks.

During April, there were 11 data point acquisitions of Channel 6 and one acquisition of Channel 7.

The two motor burns (April 11 and 26) were supported with pre- and postburn predicts.

b. Pioneer 11 Doppler Data. Doppler residuals and doppler noise values computed by the pseudoresidual program indicate the probe ephemeris tapes (PET) provided by the Pioneer 11 Navigation Team were reasonably accurate, and that doppler noise values are nominal considering the effect of increased noise due to the significant "Earth look angle" offset of the spacecraft's antenna. Figure 28 is a plot of doppler noise for Pioneer 11.

Although frequency prediction plots were not yet available, plots of Channel 6 best lock (Fig. 29) and auxiliary oscillator (TFREQ) (Fig. 30) were made.

6. Pass Chronology

The Pioneer pass chronology (Table 23) contains, in chronological sequence, information extracted from DSN Network Analysis Team (NAT) Summary reports. Abbreviations used follow as closely as possible the approved standards set forth in Ref. 7.

The format and abbreviations used in the pass chronology follow:

MONTHLY REPORT FOR (month, year)
PIONEER (spacecraft number)

GENERAL

DSS	= Station no.
PASS	= Pass no.
DOY	= Day of year
AOS	= Acquisition of signal
LOS	= Loss of signal
TOT	= Total time of track
DSS T	= Station time

COMMAND

TOT	= Command total

TELEMETRY

DL	= Downlink signal level
RES	= Residual from predicted
BR	= Bit error rate
SNR	= Signal-to-noise ratio
RES	= Residual from predicted SNR

TRACKING

MODE	= One-way, two-way, three-way
T PWR	= Transmitter power
D RES	= Doppler residual
D NOS	= Doppler noise
E NOS	= Expected noise

COMMENTS = Data on operations, anomalies, etc.

Table 17. Summary of observed Pioneer 11 mark events[a]

Mark event No.	Mark event	Nominal time (GMT)	Observed (GMT)	Observed (GMT)
	Liftoff (2 in motion)	0211:00.0		0211:00.117
1	Atlas BECO	0213:19.1	0213:20.5	0213:20.8
2	Atlas booster engine jettison	0213:22.2	0213:23.6	
3	Centaur insulation panel jettison	0214:04.1	0214:05.8M	0214:15.9T[b]
4	Sustainer engine cutoff	0215:07.9	0215:04.3M	0215:05.2T
5	Atlas/Centaur separation	0215:09.9	0215:07.7M	0215:05.2T
6	Centaur main engine start	0215:19.4	0215:17.3M	0215:18.7B
7	Nose fairing jettison	0215:31.4	0215:30.6M	0215:30.7B
8	Centaur main engine cutoff	0222:47.4	0222:44.8V	0222:45.0T
9	Third-stage spin up	0223:57.4	0223:55.1V	0223:55.3A
10	Centaur/third stage separation	0223:59.4	0223:57.7V	0223:56.9A
11	Start Centaur retrofire	0224:00.4	0223:57.7V	0223:56.9A
12	TE-364 ignition	0224:12.4	0224:11.1V	
13	TE-364 burnout	0224:56.2	0224:53.8V	
14	Pioneer separation	0226:37.4	0226:35.0V	
15	YO deploy	0226:39.4	0226:37.2V	

[a]Observing station codes:

A = AFETR/Antigua

B = STDN/Bermuda

M = STDN/Merritt Island

T = AFETR/TEL-4

V = STDN/Vanguard

[b]Mark event No. 3 was verified as recorded - apparently a time code error.

Table 18. RTCS orbital computations for Pioneer G

Type of orbit	Data source	Time of computation, min from launch	Quality of solution	Remarks
Centaur preretrofire	Antigua	20	Fair	Short data span
Centaur preretrofire	Antigua/ Vanguard	101	Good	
Centaur post-retrofire	Tananarive	115	Good	
Transfer	Vanguard	23	Fair	Ships data
Transfer	Ascension	54	Fair	Intervals of data rough
Spacecraft No. 1	DSS-51	158	Good	Retran program
Spacecraft No. 2	DSS-51	196	Good	Playmate program

Table 19. Pioneer G orbital parameters from RTCS computations

Parameters		Centaur preretrofire orbits (Antigua data)	Centaur preretrofire orbits (ANT/VAN data)	Centaur postretrofire (Based on TAN data)	Transfer orbit (Based on VAN data)	Transfer orbit (Based on ACN data)	Spacecraft orbit No. 1 (Based on DSS-51 data)	Spacecraft orbit No. 2 (Based on DSS-51 data)
Epoch time, GMT		02 22 50.2	02 22 50.2	02 24 58.6	02 24 58.6	02 24 58.6	02 24 58.6	02 24 58.6
Earth fixed sphericals	Radius, km	6541.3909	6541.5688	6607.1160	6611.6295	6610.6284	6613.5113	6610.8961
	Latitude, deg	15.701527	15.702396	9.222067	8.868700	8.865732	8.963524	8.850266
	Longitude, deg	306.41317	306.41357	316.20512	316.741802	316.742989	316.865734	316.743290
	Velocity, km/s	10.344147	10.347663	10.282796	14.041183	14.042700	14.038701	14.040280
	Path angle, deg	-0.128464	-0.167512	5.750704	5.255278	5.589184	5.621328	5.598459
	Azimuth angle, deg (000-360)	122.89859	122.92241	125.30422	124.805934	124.958407	124.954197	124.933779
Eccentricity		0.890349	0.891607	0.889146	2.447267	2.445940	2.445460	2.444964
Inclination, deg (000-360)		34.891659	34.912589	34.911588	34.735083	34.876874	34.894416	34.850074
C3		-6.681639	-6.604839	-6.754599	87.743788	87.741364	87.680406	87.680434

Table 20. Summary of Pioneer 11 command activity for April 1973

DSS	11	12	14	42	51	Total
Commands	27	240	2	844	422	1,536[a]
Aborts[b]	0	0	0	1	2	

[a]One command was sent from Ascension Island STDN station.

[b]Aborts due to Project disabling commands while CMA was in the active mode. The abort at DSS 42 was due to an error by Project in sending a command to the wrong station after a transfer of uplink. DSS 42 had command modulation and transmitter off causing the command to abort.

Table 21. TCP failures affecting command

DSS, TCP	Day of year	Pass	Down time, mins	Reason	Discrepancy Report No.
51A	097	2	18	TCP out of lock	T-2505
42A	099	4	4	TCP hung-up on bit rate change	T-2509
12B	100	5	18	Bit rate error alarms	N-0611
51A	107	12	4	TCP hung-up on format change	T-2525
51A	110	15	20	TCP hung-up (twice)	T-2531
12B	112	22	105	power failure	T-2547
51A	119	24	20	TCP hung-up at bit rate change	T-2531

Table 22. Average percent down in April (Pioneer 11)

DSS	Average, % (from 360/75 and HSD failures)	Average, % (from station failures)
11	3.7	0.8
12	4.4	3.0
14	0	0
42	1.4	0.2
51	2.9	0.4

Table 23. Pioneer 11 pass chronology for April

GENERAL									
DSS	51	72	12	42	51	72	12	42	51
PASS	001	001	001	001	002	002	002	002	003
DOY	096	096	096	096	096	097	097	097	097
AOS	0231	0226	1013	1600	2350	0902	1030	1551	2335
LOS	0558	1107	1640	0035	1000	1109	1630	0035	1025
TOT	07:27	08:41	06:27	08:35	10:10	02:07	06:00	08:44	10:50
DSS T	N/A	09:53	07:17	08:40	12:01	03:28	06:13	08:49	12:10
COMMAND									
TCT	56	0	52	8	10	1	2	4	13
TELEMETRY									
DL	115.3	N/A	N/A	133.7	136.4	N/A	138.1	141.2	143.3
RES	N/A	N/A	N/A	.4	1.3	N/A	1.8	.2	-0.3
BR	2048	N/A	N/A	1024	1024	N/A	1624	1024	1024
SNR	27.7	N/A	N/A	17.2	16.4	N/A	16.0	2.5	1.5
RES	N/A	N/A	N/A	N/A	N/A	N/A	-1.8	.8	.3
TRACKING									
MODE	2	3	2	2	2	2	2	2	2
T PWR	20	N/A	1	1	1	1	1	1	1
D RES	N/A	N/A	.198	.151	.130	N/A	.087	.079	.198
D NOS	N/A	N/A	N/A	N/A	.036	N/A	N/A	N/A	.036
E NOS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

COMMENTS

DSS 51/P 001 DR-N0608 DROPPED UPLINK DURING 2-WAY XFER DUE TO TUNING RATE TOO HIGH
DR-T2501 NAT COMMAND ENTERED INCORRECT MAXIMUM TIME OF EXECUTION CAUSING PRIORITY COMMANDS NOT TRANSMITTING

DSS 42/P 001 DSS-51 COUNT EARLY CMD TIMES:1635Z-0025Z

DSS 51/P 002 0532Z TLM PROCESS SWITCHED FROM TCP-A TO TCP-B.DR-T2505 0555Z TCP-B PRIME FOR CMD REASON FOR SWITCH WAS DDA ALPHA WAS NOT LOADED AND INITIALIZED DUE TO STATION SCHEDULED FOR INCODED DATA ONLY AND NOT EXPECTING CODED DATA

DSS 72/P 002 MONITOR DATA NOT AVAILABLE

Table 23 (contd)

GENERAL									
DSS	72	12	42	51	72	12	42	12	42
PASS	003	003	003	004	004	004	004	005	005
DOY	098	098	098	098	099	099	099	100	100
AOS	0824	1000	1554	2351	0904	1000	1552	0957	1607
LOS	1130	1631	0030	1024	1130	1631	0030	1631	0130
TCT	03:06	06:31	08:36	10:33	02:26	06:01	08:38	06:34	N/A
DSS T	03:26	06:30	10:06	11:23	03:48	07:08	10:13	N/A	N/A
COMMAND									
TCT	0	1	20	8	0	1	30	1	35
TELEMETRY									
DL	N/A	143.3	144.9	146.3	N/A	143.9	147.4	146.5	149.5
RES	N/A	1.2	.4	.0	N/A	3.4	.5	3.0	.4
BR	1024	1024	1024	1024	N/A	1024	1024	1024	1024
SNR	N/A	.2	9.5	8.5	N/A	7.9	7.8	5.7	5.6
RES	N/A	.9	.3	.0	N/A	1.6	.7	.9	.4
TRACKING									
MODE	2	2	2	2	NIL	2	2	2	2
T PWR	1	1	1	10	N/A	1	20	1	1
D RES	N/A	.242	.266	.368	N/A	.388	.397	.412	.081
D NCS	N/A	N/A	N/A	036	N/A	.038	N/A	N/A	N/A
E NCS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

COMMENTS

DSS 72/P 003	MONITOR AND TLM DATA NOT AVAILABLE
DSS 42/P 003	CDR RECALL INCLUDED
DSS 72/P 004	TLM AND MONITOR DATA NOT AVAILABLE
DSS 43/P 004	TCP-A UNABLE TO LOCK UP DR-T2509 (CD-3 BUFFER OVERFLOW OCCURRED AT BIT RATE CHANGE)
DSS 12/P 005	DR-N0611 TCP BETA B/R ALARMS
DSS 42/P 005	DSS-42 HELD OVER TO SUPPORT (PN-11 BACK UP FOR DSS-51) DR-C7127 VOICE CKT UNUSABLE

Table 23 (contd)

GENERAL									
DSS	51	42	51	12	42	51	12	42	51
PASS	006	006	007	007	007	008	008	008	009
DOY	100	101	101	102	102	102	103	103	103
AOS	2310	1549	2317	0951	1640	2329	0945	1633	2234
LOS	1017	2350	1013	1700	2350	1010	1700	2246	0906
TOT	11:07	08:01	10:56	07:09	07:10	10:41	07:15	06:13	10:32
DSS T	11:49	09:45	11:46	N/A	07:50	12:15	08:11	06:28	12:37
COMMAND									
TOT	96	110	24	2	41	24	1	61	45
TELEMETRY									
DL	136.7	148.5	149.0	148.3	148.2	150.4	150.2	151.1	149.2
RES	-1.4	1.8	-0.1	1.1	1.5	-0.3	-0.1	0.0	.4
BR	512	1024	1024	N/A	1024	1024	1024	1024	1024
SNR	5.3	7.1	6.2	5.4	5.8	5.0	3.8	4.6	6.6
RES	1.0	.4	.5	.4	.4	.6	.6	-.3	.4
TRACKING									
MODE	2	2		2	2	2	2	2	2
T PWR	10	1	1	1	1	1	1	1	1
D RES	.409	1.272	1.353	N/A	1.374	1.436	N/A	1.435	1.524
D NCS	N/A	.012	.012	N/A	.012	.012	N/A	.012	N/A
E NCS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

COMMENTS

DSS 51/P 006 I-NOTE-2 CMDS DISABLED BY PROJ WHILE CAUSING ABORTS

DSS 42/P 008 1901Z-1915Z COMM-OUTAGE,IPP CMDING DELAYED,DR-N0615

Table 23 (contd)

GENERAL									
DSS	11	42	51	11	42	51	11	42	51
PASS	009	009	010	010	010	011	011	011	012
DOY	104	104	104	105	105	105	106	106	106
AOS	1023	1619	2249	1020	1549	2255	1016	1600	2334
LOS	1635	2329	1002	1625	2320	0558	1625	2351	0954
TOT	06:12	07:10	11:13	06:05	07:31	11:03	06:09	07:51	10:20
DSS T	N/A	07:15	11:55	07:17	08:44	11:28	N/A	09:00	11:11
COMMAND									
TCT	4	54	1	0	2	2	4	6	57
TELEMETRY									
DL	149.5	147.8	149.8	149.3	150.1	N/A	149.7	151.1	151.9
RES	.1	1.8	.8	1.3	.5	N/A	1.8	.4	.4
BR	1024	1024	1024	1024	1024	1024	1024	512	512
SNR	5.1	7.1	5.7	4.4	5.7	4.5	4.1	7.5	6.6
RES	.2	.7	.5	.5	.3	.2	.8	.0	.1
TRACKING									
MODE	2	2	2	2	2	2	2	2	2
T PWR	1	1	1	1	1	1	1	1	1
D RES	1.525	1.505	1.588	1.576	1.564	1.641	1.526	1.64	1.713
D NOS	.012	.009	N/A	.009	.010	.010	.009	.008	.010
E NOS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

COMMENTS

DSS 42/P 009	1804Z-1805Z.STA RX HSD LOSTLOCK.22 MIN DELAY IN IPP COMMANDING DR-N-0617
DSS 42/P 011	FAR P-0201 3100'S AND GOOD 4800 DR 1621Z-1757Z
	FAR P-0202 360/75-B DN 1745Z-1752Z
	FAR P-0202 360/75-B DN 1802Z-1813Z
DSS 51/P 012	DRT-2525 TCP-A WOULDN'T ACCEPT FORMAT CHANGE
	DR-N0619 REF DR-C7149 DELAY OF CMD MSG 001-01 25 MINS DUE TO COMM OUTAGE

Table 23 (contd)

GENERAL									
DSS	11	42	51	11	42	51	14	11	51
PASS	012	012	013	013	013	014	014	014	015
DOY	107	107	107	108	108	108	109	109	109
AOS	1013	1600	2315	1007	1555	2325	1052	1220	2322
LOS	1625	2351	0949	1624	0000	0946	1237	1605	0941
TCT	06:20	07:51	10:34	06:20	08:05	10:21	01:45	03:45	10:19
DSS T	07:17	11:09	12:08	07:18	09:20	11:56	01:57	05:04	11:30
COMMAND									
TCT	4	58	1	1	2	4	2	2	7
TELEMETRY									
DL	151.1	152.2	152.7	151.2	152.7	153.2	N/A	N/A	153.8
RES	1.2	.1	.3	1.8	.3	.7	N/A	N/A	.5
BR	512	512	512	512	512	512	1024	256	512
SNR	5.2	6.7	6.1	4.8	.4	5.7	N/A	5.8	5.2
RES	.3	.1	.3	.3	.4	.6	N/A	.1	.8
TRACKING									
MODE	2	2	2	2	2	2	2	2	2
T PWR	1	1	10	10	10	10	1	10	10
D RES	1.664	.718	1.792	1.620	1.649	1.755	N/A	1.861	1.837
D NCS	.009	.009	.010	.006	.013	.010	.011	.011	.008
E NCS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

COMMENTS

DSS 11/P 012	DRT-2526 ANTENNA DROVE OFF S/C
DSS 42/P 013	1623Z-ECT UPLINK JITTER RESULTING IN DOWNLINK GLITCHES DR-T2528 CAUSED BY FAULTY ACQUISITION POWER SUPPLY IN EXCITER
DSS 11/P 014	COMMERCIAL POWER PROBLEM CAUSED S-L TO BE INACCURATE AND LATE ACQUISITION MASSIVE POWER FAILURE AT GOLDSTONE COMPLEX CAUSED EXCESSIVE EQUIPMENT DAMAGE TO TCP.DDA AND DIS AND BOTH MASERS
DSS 51/P 015	DRT-2531HSD OUTPUT FROM TCP ALPHA HUNGUP REQ'ING RELOAD

Table 23 (contd)

GENERAL									
DSS	11	42	51	12	42	51	12	42	51
PASS	015	015	016	016	016	017	017	017	018
DCY	110	110	110	111	111	111	112	112	112
ACS	1005	1555	2319	0910	1546	2320	0905	1503	2313
LCS	1610	2400	0936	1620	3522	0932	1520	2355	0925
TOT	06:05	08:05	10:17	07:10	08:06	10:12	06:15	08:52	10:12
DSS T	07:36	09:45	12:14	N/A	09:49	11:10	N/A	10:35	11:17
COMMAND									
TCT	4	37	6	1	55	2	1	3	2
TELEMETRY									
DL	153.6	153.6	153.7	152.3	153.4	154.4	153.2	153.8	155.2
RES	.7	.7	1.2	2.6	1.5	1.1	2.3	1.2	.8
BR	256	256	512	512	512	512	256	512	512
SNR	5.2	7.2	4.7	4.4	4.8	3.9	5.8	4.4	3.7
RES	0.2	.0	.8	1.8	.8	.6	1.4	1.0	.9
TRACKING									
MODE	2	2	2	2	2	2	2	2	2
T PWR	10	10	10	10	10	10	10	10	10
D RES	1.788	1.832	1.927	1.900	1.955	2.037	2.036	2.080	2.183
D NCS	010	.003	.011	.010	.005	.007	.010	.006	.011
E NCS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

COMMENTS

DSS 12/P 016 CR-T2534 BLOWN S/C TRANFER DUE TO SMC75 FREQ PROB
CR-N0623 BOTH TCP'S INITIALIZED AS ALPHA FOR CMD.
CR-T2535 INVALID TLM FROM TCP-A

DSS 42/P 016 2106Z,CMD MSG 012-07 FAILED TO XMIT,IN STK AND ENABLED
DR-N0624 TIMING PROB IN SEC'S FAILED OF TRACKING HSD
CR-N0625

ORIGINAL PAGE IS
OF POOR QUALITY

Table 23 (contd)

GENERAL									
DSS	12	42	51	12	42	51	12	42	51
PASS	018	018	019	019	019	020	020	020	021
DOY	113	113	113	114	114	114	115	115	115
AOS	0859	1549	2229	0855	1555	2220	0900	1544	2116
LOS	1620	2250	0920	1620	2245	0915	1620	2245	0915
TOT	07:21	07:01	10:51	07:25	06:50	10:55	07:20	07:01	11:59
DSS T	08:20	08:27	12:01	N/A	08:12	11:37	08:33	08:33	12:49
COMMAND									
TOT	8	53	9	2	34	24	54	10	2
TELEMETRY									
DL	152.8	N/A	150.8	150.4	150.1	151.2	150.1	150.4	151.2
RES	3.2	N/A	-0.3	.1	.4	-0.8	-0.3	.0	-0.3
BR	256	256	512	1024	1024	1024	1024	1024	1024
SNR	5.5	N/A	5.3	4.7	5.6	5.1	3.2	5.5	4.8
RES	1.1	N/A	.1	0.9	.1	.1	.2	.0	.0
TRACKING									
MODE	2	2	2	2	2	2	2	2	2
T PWR		10	10	10	10	10	10	10	10
D RES	2.170	2.232	.285	.280	.273	.292	.278	.273	.290
D NOS	.010	.003	.004	.006	.005	.006	.006	.0055	.006
E NOS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

COMMENTS

DSS 42/P 018 TLM NOT AVAILABLE DUE TO PROCESSING MANEUVER

DSS 12/P 020 1502Z-1513Z DCA"B"FAILED,DR-T2541
1513Z-1615Z WRONG BIT RATE IN HISPEED DATA WORDS
15,23,31,39,D T2542
1513Z FORMAT ASSIGNMENTS TO VZKD,VZLD AND VZMD WRONG
APPARENTLY DUE TO A T-MED ENTRY FOR PROCESS CHANGE
FROM TCP B TO A
FAR P0218 & D0594 GENER ON HAVING TO DO A T-30 INIT
THESE IMPACED ON ABOVE PROBLEM

DSS 51/P 021 360 PROBLEMS REF. FAR-P-0221

Table 23 (contd)

GENERAL									
DSS	12	42	51	12	42	51	11	42	51
PASS	021	021	022	022	022	023	023	023	024
DOY	116	116	116	117	117	117	118	118	118
AOS	0850	1555	2210	0850	1553	2215	0931	1500	2200
LOS	1615	2241	0910	1610	0141	0907	1520	2235	0904
TOT	07:25	06:46	11:00	07:20	09:48	10:52	05:49	07:35	11:04
DSS T	08:31	08:23	11:34	08:50	09:51	11:53	06:35	09:5M	12:17
COMMAND									
TCT	8	47	1	11	61	1	7	0	4
TELEMETRY									
DL	150.7	152.3	152.0	151.2	151.4	151.8	151.7	151.9	152.2
RES	.2	-1.4	-0.7	.1	-.1	-0.1	.0	-0.2	-0.2
BR	1024	1024	1024	1024	1024	1024	512	512	512
SNR	3.8	5.1	4.7	3.6	3.4	4.2	7.4	6.5	6.6
RES	.2	.0	.1	.2	.1	.3	1.3	.8	.3
TRACKING									
MODE	2	2	2	2	2	2	2	2	2
T PWR	10	10	10	10	10	10	10	10	10
D RES	.277	.302	.311	N/A	.317	.327	.306	.332	.338
D NCS	005	.005	.007	.007	.007	.007	.007	.006	.007
E NCS	.003	.004	.004	N/A	.005	N/A	N/A	N/A	N/A

COMMENTS

DSS 12/P 021	MISSED LOST LOG WRITE READINGS
DSS 12/P 022	1234Z-1235Z STATION POWER FAILURE DR-T2547
DSS 42/P 022	1936Z-1941Z 36C DOWN FAR P-0224
DSS 51/P 023	DR-C7179 HSDL DOWN 2215Z-0143Z.
	DR-0631 EXCESSIVE WRITE ERRORS ON DIS
DSS 11/P 023	TLM DATA FOR MAJORITY OF PASS WAS UNCODED.
	LOSS OF TLM PN SYN THRU-OUTPASS. DR-T2550.
DSS 51/P 024	DCA ALPHA ALARMS 1000 & 20 REQ'ING TCP RELOAD DR-T2531

Table 23 (contd)

GENERAL						
DSS	11	42	51	12	42	51
PASS	024	024	025	025	025	026
DOY	119	119	119	120	120	120
AOS	0927	1211	2146	0845	1457	2157
LOS	1230	2225	0855	1520	2221	0849
TOT	03:03	10:14	11:09	06:35	07:24	10:52
DSS T	03:25	11:35	12:21	07:39	08:58	12:38
COMMAND						
TOT	1	12	15	10	5	2
TELEMETRY						
DL	151.9	151.9	152.0	152.4	152.3	152.5
RES	.1	.1	.4	.0	.1	.2
BR	512	1024	512	512	512	1024
SNR	7.6	4.2	3.6	4.8	6.2	3.3
RES	.6	.1	.5	.6	.4	.4
TRACKING						
MODE	2	2	2	2	2	2
T PWR	10	10	10	10	10	10
D RES	N/A	.348	.363	.339	.349	.369
D NOS	.007	.007	.007	.007	.007	.006
E NOS	N/A	.005	N/A	N/A	N/A	N/A

COMMENTS

DSS 11/P 024 DIS DOWN SHORTLY AFTER 1100Z FOR USE IN TROUBLE SHOOTING PN-SY PROB. REFER DR-T2550
DR-T2550-BIT SHIFT IN PN-SYNC WORD.DATA UNUSABLE.
1230Z STATION RELEASED TO TROUBLE SHOOT

DSS 51/P 025 DR-C7183 HSDL OUTAGE 120/0353Z-120/0428Z,ONE CMD SENT IN MANUAL MODE (004-C1)

DSS 12/P 025 1020Z-1043Z DATA BAD IN UNCODED SAME SYMPTOMS AS NOTED FROM DSS-11 ONDOY 118/119

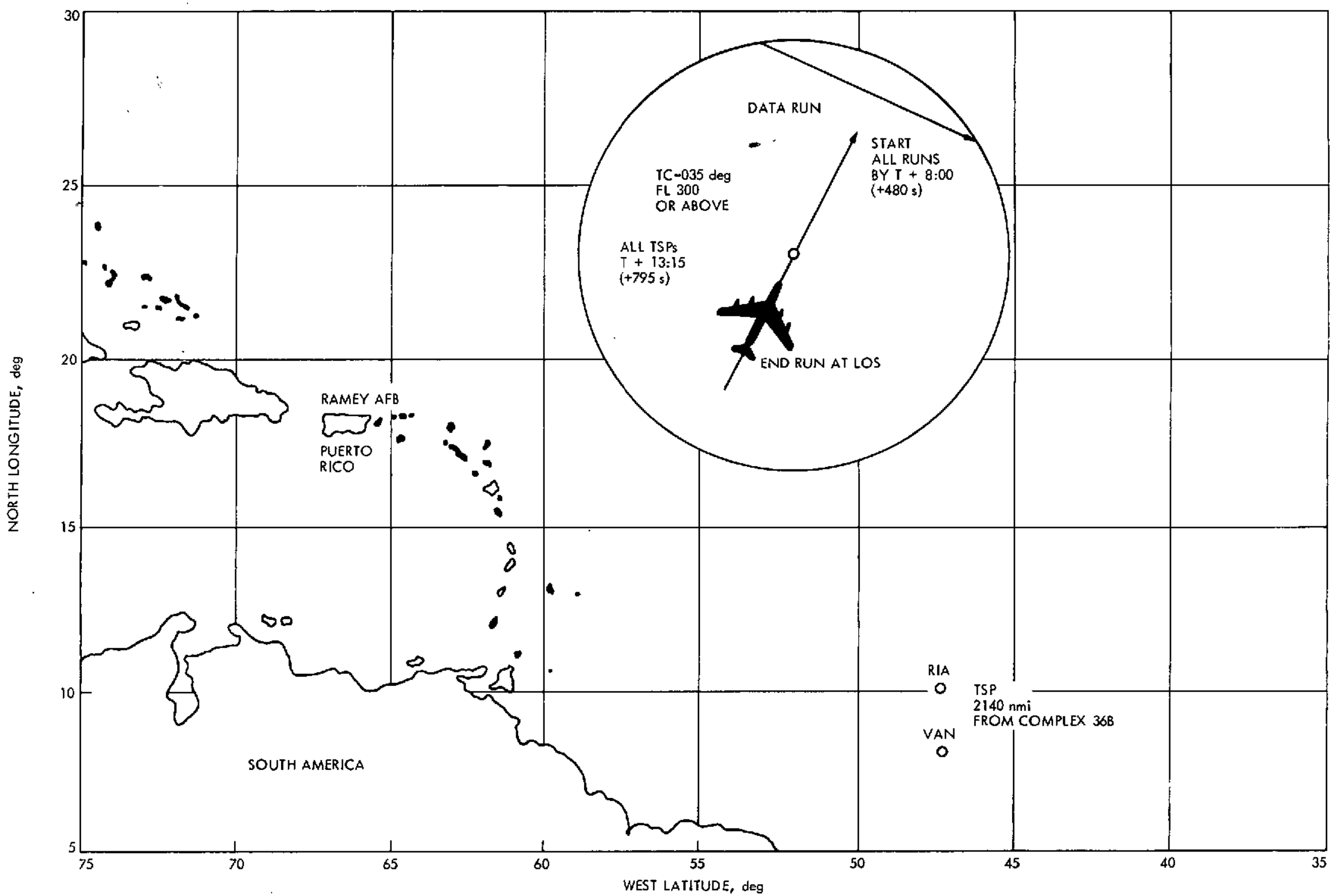


Fig. 22 Ship and aircraft support positions

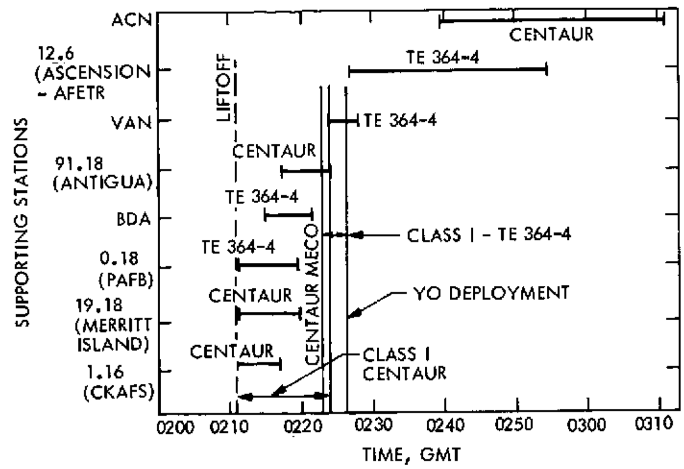


Fig. 23. C-band metric data coverage

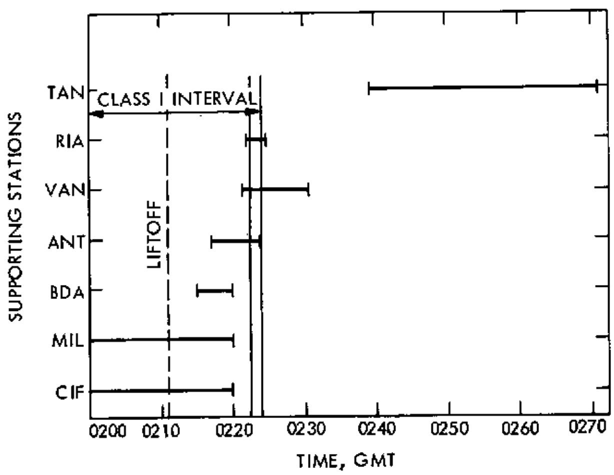


Fig. 24. Centaur telemetry data coverage

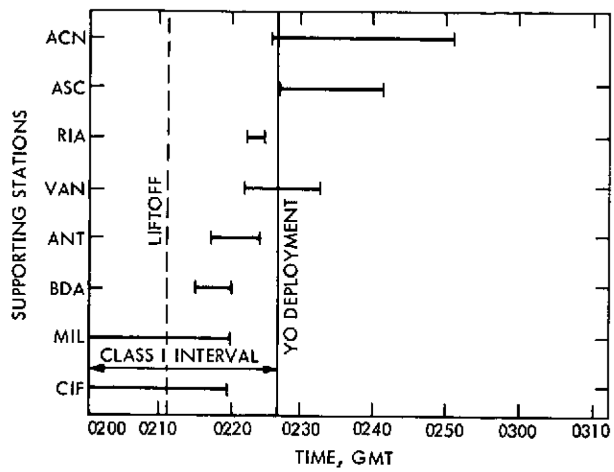


Fig. 25. TE-364-4 telemetry data coverage

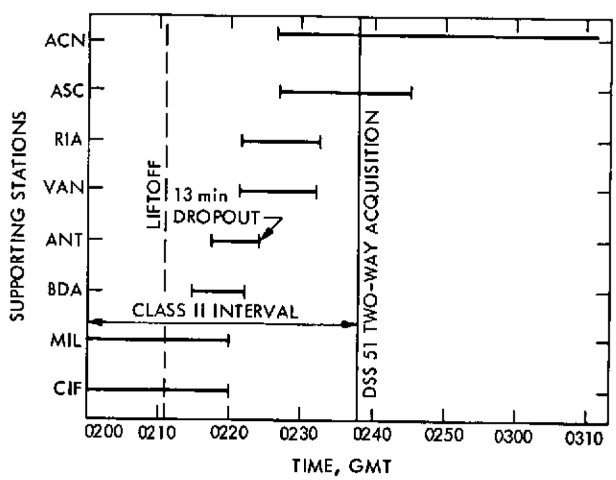


Fig. 26. Spacecraft telemetry data coverage

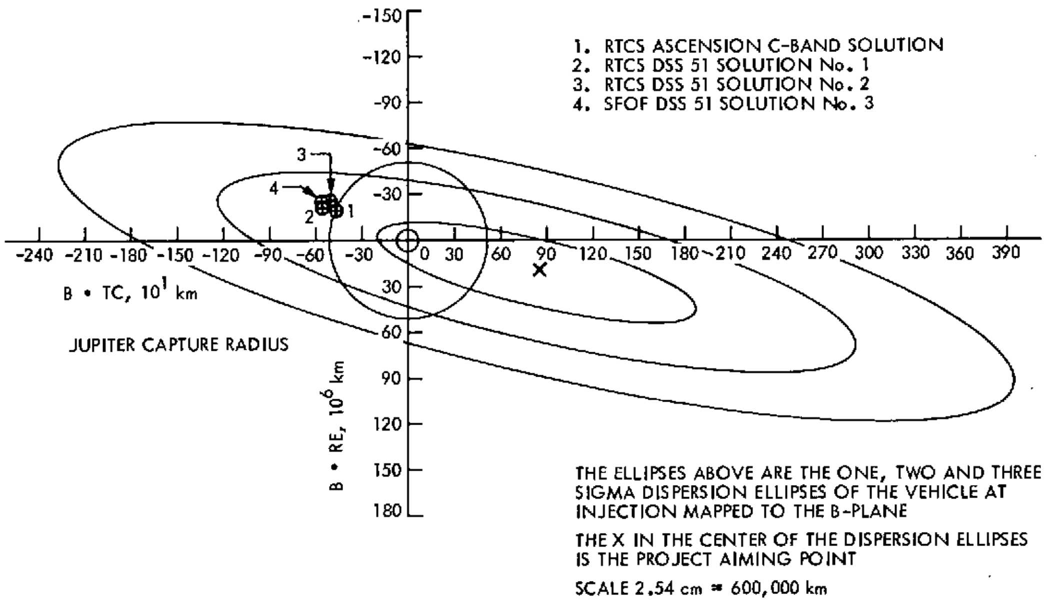


Fig. 27. Jupiter B-plane maps of RTCS and SFOF solutions during first four hours after launch

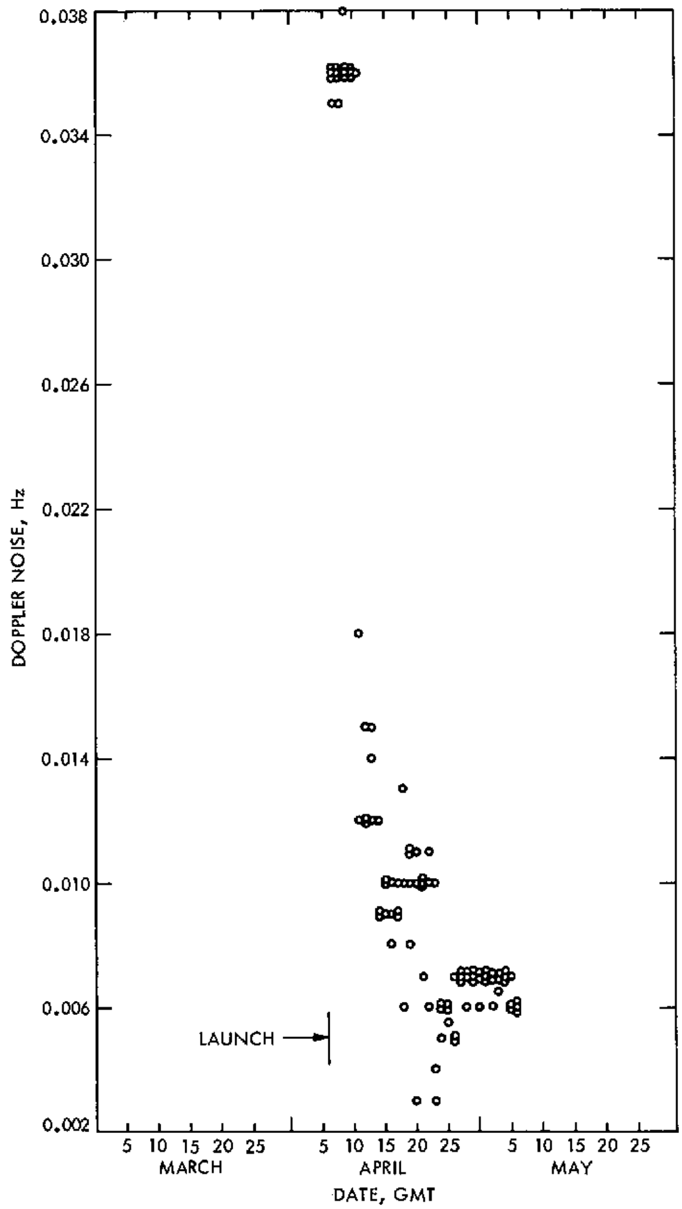


Fig. 28. Pioneer 11 doppler noise plot

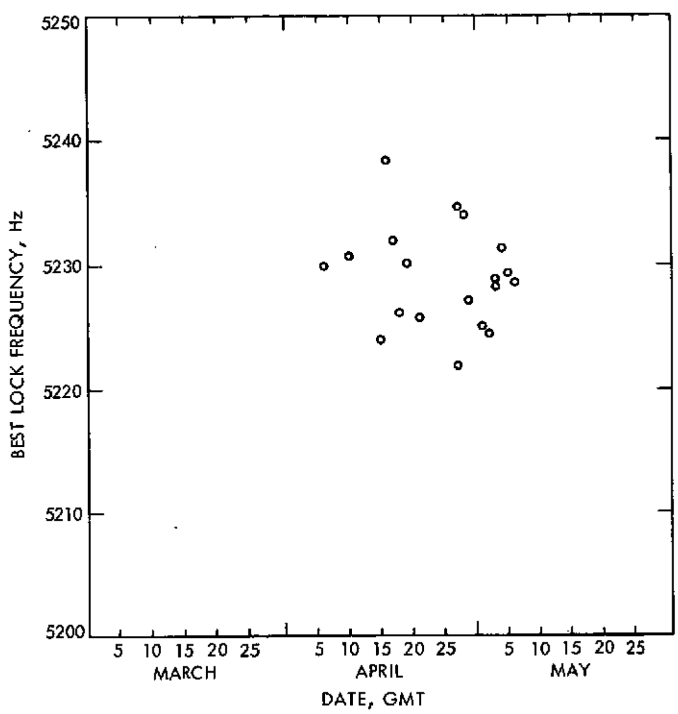


Fig. 29. Pioneer 11 channel 6 best lock frequency

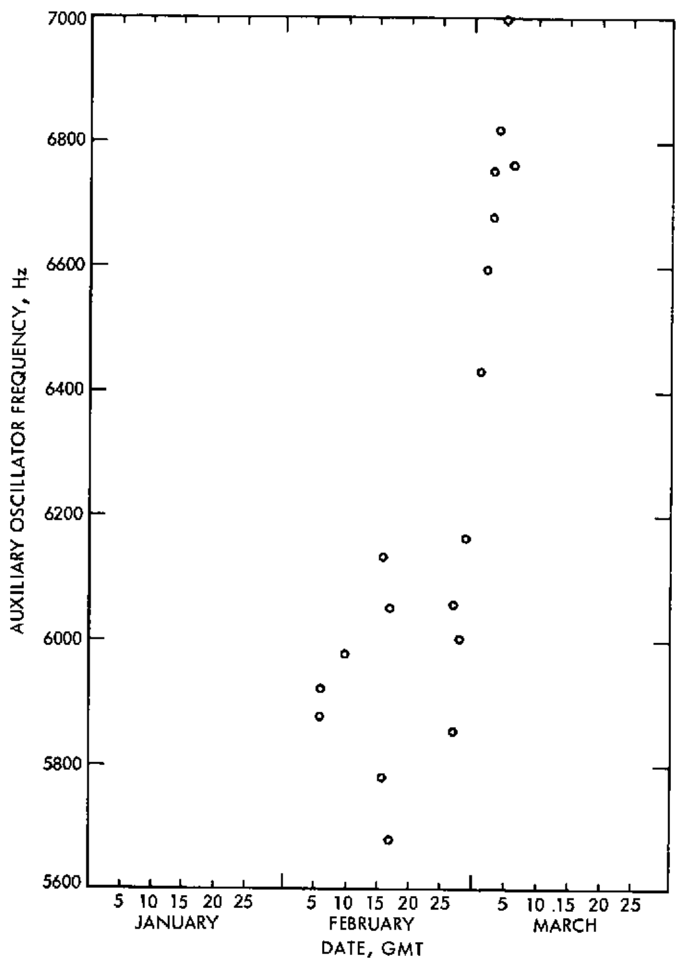


Fig. 30. Pioneer 11 auxiliary oscillator frequency

REFERENCES

1. Siegmeth, A.J., Purdue, R.E., and Ryan, R.E., Tracking and Data System Support for the Pioneer Project: Volume I. Pioneer 10 – Prelaunch Planning Through Second Trajectory Correction December 4, 1969 to April 1, 1972, Technical Memorandum 33-584. Jet Propulsion Laboratory, Pasadena, California, April 1, 1973.

2. Project Pioneer 10 and 11 Support Instrumentation Requirements Document. NASA Ames Research Center, Pioneer Project Office, Moffett Field, California; Revision 5: June 1972; Revision 6: September 1972.

3. Pioneer 10 and 11 NASA Support Plan, Revision 1. Jet Propulsion Laboratory, Pasadena, California, April 1973 (JPL internal document).

4. TDS Near-Earth Phase Operations Plan for Pioneer G Project: Volume II. Near-Earth Phase Interface Description, Document No. 616-38. Jet Propulsion Laboratory, Pasadena, California, Feb. 15, 1973 (JPL internal document).

5. TDS Near-Earth Phase Operations Plan for Pioneer G Project: Volume III. Near-Earth Phase Systems Descriptions, Document No. 616-32. Jet Propulsion Laboratory, Pasadena, California, Oct. 15, 1972 (JPL internal document)

6. TDS Near-Earth Test Plan, Document No. 616-36. Jet Propulsion Laboratory, Pasadena, California, Dec. 1, 1972 (JPL internal document).

7. DSN Standard Practice: Glossary of Deep Space Network Abbreviations and Designators, Document 810-3, Rev. A. Jet Propulsion Laboratory, Pasadena, California, Sept. 1, 1971 (JPL internal document).

Bibliography

Anderson, J. D., Null, G. W., and Thornton, C. T., *The Evaluation of Certain Astronomical Constants from the Radio Tracking of Mariner II*, Technical Report 32-476, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *Progr. Astronaut. Aeronaut.*, Vol. 14, 1964.

Anderson, J. D., *Determination of the Masses of the Moon and Venus and the Astronomical Unit from Radio Tracking Data of the Mariner II Spacecraft*, Technical Report 32-816, Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1967.

Anderson, J. D., et al., "The Radius of Venus as Determined by Planetary Radar and Mariner V Radio Tracking Data," *J. Atmos. Sci.*, pp. 1171–1174, Sept. 25, 1968.

Anderson, J. D., and Hilt, D. E., "Improvement of Astronomical Constants and Ephemerides from Pioneer Radio Tracking Data," *AIAA J.*, Vol. 7, No. 6, pp. 1048–1054, June 1969.

Anderson, J. D., "Determination of Astrodynamic Constants and a Test of the General Relativistic Time Delay With S-Band Range and Doppler Data From Mariners 6 and 7," *Space Research*, Vol. XI, pp. 105–112, Akademie-Verlag, Berlin, 1971.

Barnum, P. W., et al., *Tracking and Data System Support for the Mariner Mars 1971 Mission: Orbit Insertion Through End of Primary Mission*, Technical Memorandum 33-523, Vol. III, Jet Propulsion Laboratory, Pasadena, Calif., May 15, 1973.

Barnum, P. W., and Renzetti, N. A., *Tracking and Data System Support for the Mariner Mars 1971 Mission: Extended Mission Operations*, Technical Memorandum 33-523, Vol. IV, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1973.

Bathker, D. A., *Radio-Frequency Performance of an 85-ft Ground Antenna: X-Band*, Technical Report 32-1300, Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1968.

Bathker, D. A., *Radio Frequency Performance of a 210-ft Ground Antenna: X-Band*, Technical Report 32-1417, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1969.

Bathker, D. A., *Predicted and Measured Power Density Description of a Large Ground Microwave System*, Technical Memorandum 33-433, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1971.

Baumert, L., et al., *Coding Theory and Its Applications to Communications Systems*, Technical Report 32-67, Jet Propulsion Laboratory, Pasadena, Calif., Mar. 31, 1961.

Baumgartner, W. S., *High-Power CW Radar Transmitter*, Technical Report 32-656, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1964.

Berman, A. L., *Tracking System Data Analysis Report, Ranger VII Final Report*, Technical Report 32-719, Jet Propulsion Laboratory, Pasadena, Calif., June 1, 1965.

Biber, K. W., and Whittlesey, A. C., *Description and Analysis of 890-MHz Noise-Measuring Equipment*, Technical Report 32-898, Jet Propulsion Laboratory, Pasadena, Calif., Mar. 31, 1966.

Brockman, M. H., and Posner, E. C., *Power Requirements for Deep-Space Telecommunication Links*, Technical Report 32-1395, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Spectrum*, Vol. 6, No. 3, pp. 95–99, Mar. 1969.

Bunce, R. C., *Unified S-Band Receiver-Exciter Subsystem*, Technical Report 32-809, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 15, 1968.

Butman, S., "A General Formulation of Linear Feedback Communication Systems with Solutions," *IEEE Trans. Inform. Theor.*, Vol. IT-15, No. 3, pp. 392–400, May 1969.

Butman, S., "Rate Distortion Over Band-Limited Feedback Channels," *IEEE Trans. Inform. Theor.*, Vol. IT-17, No. 1, pp. 110–112, Jan. 1971.

Butman, S., and Timor, U., "Interplex—An Efficient Multichannel PSK/PM Telemetry System", *IEEE Trans. Commun.*, Vol. COM-20, No. 3, pp. 415–419, June 1972.

Cain, D. L., and Hamilton, T. W., *Determination of Tracking Station Locations by Doppler and Range Measurements to an Earth Satellite*, Technical Report 32-534, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 1, 1964.

Carey, C. N., and Sjogren, W. L., *Gravitational Inconsistency in the Lunar Theory: Confirmation by Radio Tracking*, Technical Report 32-1290, Pt. II, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *Science*, Vol. 160, No. 3830, pp. 875–876, May 24, 1968.

Carpenter, R. L., *Study of Venus by CW Radar—1964 Results*, Technical Report 32-963, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *Astron. J.*, Vol. 71, No. 2, pp. 142–152, Mar. 1966.

Chadwick, H. D., and Springett, J. C., "The Design of a Low Data Rate MSFK Communication System," *IEEE Trans. Commun. Technol.*, Vol. COM-18, No. 6, pp. 740–750, Dec. 1970.

Chaney, W. D., *Final Mariner II Tracking System Data Analysis Report*, Technical Report 32-727, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1965.

Charles, F. J., and Lindsey, W. C., *Some Analytical and Experimental Phase-Locked Loop Results for Low Signal-to-Noise Ratios*, Technical Report 32-1027, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *Proc. IEEE*, Vol. 54, No. 9, pp. 1152–1166, Sept. 1966.

Clark, B. G., et al., "High Resolution Observations of Compact Radio Sources at 13 cm," *Astrophys. J.*, Vol. 161, pp. 803–809, Sept. 1970.

Clauss, R. C., et al., *Total System Noise Temperature: 15°K*, Technical Report 32-691, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 1964.

Clauss, R. C., *A 2388-Mc Two-Cavity Maser for Planetary Radar*, Technical Report 32-583, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *Microwave J.*, Vol. 8, pp. 74–77, May 1965.

Clauss, R. C., *A Traveling Wave Maser for Deep Space Communication at 2295 and 2388 MHz*, Technical Report 32-1072, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 15, 1967.

Cohen, M. H., et al., "Compact Radio Source in the Nucleus of M87," *Astrophys. J.*, Vol. 158, No. 2, Pt. 2, pp. L83–L85, Nov. 1969.

Coyner, J. V., Jr., *Radial Rib Antenna Surface Deviation Analysis Program*, Technical Memorandum 33-518, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1971.

Curkendall, D. W., and McReynolds, S. R., "A Simplified Approach for Determining the Information Content of Radio Tracking Data," *J. Spacecraft Rockets*, Vol. 6, No. 5, pp. 520–525, May 1969.

Curkendall, D. W., and Stephenson, R. R., "Earthbased Tracking and Orbit Determination—Backbone of the Planetary Navigation System," *Astronaut. Aeronaut.*, Vol. 7, No. 5, pp. 30–36, May 1970.

Curkendall, D. W., "Planetary Navigation: The New Challenges," *Astronaut. Aeronaut.*, Vol. 7, No. 5, pp. 26–29, May 1970.

"The Deep Space Network—An Instrument for Radio Navigation for the Mariner Mission to Mars—1969," *Proceedings of the Second International Conference of STM and AERA*, Reidel Publishing Company, Holland, May 1969.

Description of the Deep Space Network Operational Capabilities as of January 1, 1966, Technical Memorandum 33-255, Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1966.

Didday, R. L., and Lindsey, W. C., *Subcarrier Tracking Methods and Communication System Design*, Technical Report 32-1317, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Trans. Commun. Technol.*, Vol. COM-16, No. 4, pp. 541–550, Aug. 1968.

Downs, G. S., and Reichley, P. E., "Observations of Interstellar Scintillations of Pulsar Signals at 2388 MHz," *Astrophys. J.*, Vol. 163, No. 1, Pt. 2, pp. L11–L16, Jan. 1971.

Downs, G. S., et al., "Mars Radar Observation, A Preliminary Report," *Science*, Vol. 174, No. 4016, pp. 1324–1327, Dec. 24, 1971.

Easterling, M., *A Long-Range Precision Ranging System*, Technical Report 32-80, Jet Propulsion Laboratory, Pasadena, Calif., July 10, 1961.

Easterling, M., *Methods for Obtaining Velocity and Range Information from CW Radars*, Technical Report 32-657, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1964.

Easterling, M., and Goldstein, R., *The Effect of the Interplanetary Medium on S-Band Telecommunications*, Technical Report 32-825, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1965.

Efron, L., and Solloway, C. B., *Proceedings of the Conference on Scientific Applications of Radio and Radar Tracking in the Space Program*, Technical Report 32-1475, Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1970.

Esposito, P. B., and Wong, S. K., "Geocentric Gravitational Constant Determined from Mariner 9 Radio Tracking Data," paper presented at the International Symposium on Earth Gravity Models (American Geophysical Union, NASA), St. Louis, Aug. 1972.

Fearey, J. P., and Renzetti, N. A., "Navigation Results on the Mariner Mars Mission to Mars 1969," International Navigation Conference, Hamburg, Oct. 1969.

Fjeldbo, G., Kliore, A. J., and Seidel, B. L., "Bistatic Radar Measurements of the Surface of Mars with Mariner 1969," *Icarus*, Vol. 16, No. 3, pp. 502–508, June 1972.

Fjeldbo, G., and Eshleman, V. R., "Radio Occultation Measurements and Interpretations," in *The Atmospheres of Venus and Mars*, p. 225, Gordon and Breach, Science Publishers, Inc., New York, N.Y., 1968.

Flanagan, F. M., et al., *Deep Space Network Support of the Manned Space Flight Network for Apollo: 1962–1968*, Technical Memorandum 33-452, Vol. I, Jet Propulsion Laboratory, Pasadena, Calif., July 1970.

Flanagan, F. M., et al., *Deep Space Network Support of the Manned Space Flight Network for Apollo: 1969–1970*, Technical Memorandum 33-452, Vol. II, Jet Propulsion Laboratory, Pasadena, Calif., May 1, 1971.

Fredricksen, H., *Error Correction for Deep Space Network Teletype Circuits*, Technical Report 32-1275, Jet Propulsion Laboratory, Pasadena, Calif., June 1, 1968.

Georgevic, R. M., *Mathematical Model of the Solar Radiation Force and Torques Acting on the Components of a Spacecraft*, Technical Memorandum 33-494, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 1, 1971.

Goldstein, R., Stevens, R., and Victor, W. K., *Radar Exploration of Venus: Goldstone Observatory Report for October–December 1962*, Technical Report 32-396, Jet Propulsion Laboratory, Pasadena, Calif., Mar. 1, 1965.

Goldstein, R. M., *The Analysis of Uncooperative Radar Targets*, Technical Report 32-658, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1964.

Goldstein, R. M., et al., *The Superior Conjunction of Mariner V*, Technical Report 32-1092, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 1, 1967.

Goldstein, R. M., "Radar Time-of-Flight Measurements to Venus," *Astron. J.*, Vol. 73, No. 9, Aug. 1968.

Goldstein, R. M., et al., "Preliminary Radar Results of Mars," *Radio Sci.*, Vol. 5, No. 2, pp. 475–478, Feb. 1970.

Goldstein, R. M., and Rumsey, H., "A Radar Snapshot of Venus," *Science*, Vol. 169, Sept. 1970.

Goldstein, R. M., "Radar Observations of Mercury," *Astron. J.*, Vol. 76, No. 10, pp. 1152–1154, Dec. 1971.

Golomb, S. W., "New Problems of Space Communications: Part I. Beware of the Tigers," *Astronautics*, Vol. 7, No. 6, p. 19, June 1962.

Golomb, S. W., "New Problems in Space Communications: Part 3," *Astronautics*, Vol. 7, No. 8, p. 26, Aug. 1962.

Golomb, S. W., "Ferreting Signals Out of Noise," *Int. Sci. Technol.*, No. 22, pp. 72–82 and 120, Oct. 1963.

Gordon, H. J., et al., *The Mariner 6 and 7 Flight Paths and Their Determination From Tracking Data*, Technical Memorandum 33-469, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 1, 1970.

Gottlieb, P., et al., "Lunar Gravity over Large Craters from Apollo 12 Tracking Data," *Science*, Vol. 168, No. 3930, pp. 477–479, Apr. 1970.

Gray, R. M., and Tausworthe, R. C., "Frequency-Counted Measurements, and Phase Locking to Noise Oscillators," *IEEE Trans. Commun. Technol.*, Vol. COM-19, No. 1, pp. 21–30, Feb. 1971.

Gubbay, J., et al., "Variations of Small Quasar Components at 2,300 MHz," *Nature*, Vol. 224, No. 5224, pp. 1094–1095, Dec. 1969.

Gulkis, S., and Gary, B., "Circular Polarization and Total-Flux Measurements of Jupiter at 13.1 cm Wavelength," *Astron. J.*, Vol. 76, No. 1, pp. 12–16, Feb. 1971.

Hall, J. R., *Tracking and Data System Support for Lunar Orbiter*, Technical Memorandum 33-450, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 1970.

Hamilton, T. W., et al., *The Ranger IV Flight Path and Its Determination From Tracking Data*, Technical Report 32-345, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 15, 1962.

Hartop, R. W., *Power Loss Between Arbitrarily Polarized Antennas*, Technical Report 32-457, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1964.

Havens, W. F., et al., *Scan Pointing Calibration for the Mariner Mars 1971 Spacecraft*, Technical Memorandum 33-556, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 1, 1972.

Heftman, K., and Renzetti, N. A., "Data Return Capabilities of the Deep Space Network in the 1970's," AIAA Paper 67-648, *Proceedings of the AIAA Space Program Issues of the 70's Meeting*, Aug. 1967.

Higa, W. H., *Low-Level Microwave Mixing in Ruby*, Technical Report 32-1016, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *Proc. IEEE*, Vol. 54, No. 10, p. 1453, Oct. 1966.

Higa, W. H., "Time Synchronization via Lunar Radar," *Proc. IEEE*, Vol. 60, No. 5, pp. 552–557, May 1972.

Holmes, J. K., "On a Solution to the Second-Order Phase-Locked Loop," *IEEE Trans. Commun. Technol.*, Vol. COM-18, No. 2, pp. 119–126, Apr. 1970.

Holmes, J. K., "First Slip Times Versus Static Phase Error Offset for the First and Passive Second-Order Phase-Locked Loop," *IEEE Trans. Commun. Technol.*, Vol. COM-19, No. 2, pp. 234–235, Apr. 1971.

Holmes, J. K., and Tegnelia, C. R., *Digital Command System Second-Order Subcarrier Tracking Performance*, Technical Report 32-1540, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 1, 1971.

Holmes, J. K., "Performance of a First Order Transition Sampling Digital Phase-Locked Loop Using Random-Walk Models," *IEEE Trans. Commun.*, Vol. COM-20, No. 2, pp. 119–131, Apr. 1972.

Hurd, W. J., and Anderson, T. O., *Digital Transition Tracking Symbol Synchronizer for Low SNR Coded Systems*, Technical Report 32-1488, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Trans. Commun. Technol.*, Vol. COM-18, No. 2, pp. 141–147, Apr. 1970.

Jaffe, R., and Rechtin, E., *Design and Performance of Phase-Lock Loops Capable of Near-Optimum Performance over a Wide Range of Input Signal and Noise Levels*, Progress Report 20-243, Jet Propulsion Laboratory, Pasadena, Calif., Dec.

1, 1954; also available in *IRE Trans. Inform. Theory*, No. 1, pp. 66–67, Mar. 1955.

Jordan, J. F., "Orbit Determination for Powered Flight Space Vehicles on Deep Space Missions," *J. Spacecraft Rockets*, Vol. 6, No. 5, pp. 545–550, May 1969.

Kellerman, K. I., et al., "High Resolution Observations of Compact Radio Sources at 13 Centimeters," *Astrophys. J.*, Vol. 161, No. 3, pp. 803–809, Sept. 1970.

Kelly, A. J., *Microwave Probe for Plasma Plumes*, Technical Report 32-625, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 1965.

Kliore, A., Cain, D. L., and Hamilton, T. W., *Determination of Some Physical Properties of the Atmosphere of Mars from Changes in the Doppler Signal of a Spacecraft on an Earth-Occultation Trajectory*, Technical Report 32-674, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 15, 1964.

Kliore, A., and Tito, D. A., *Radio Occultation Investigations of the Atmosphere of Mars*, Technical Report 32-1157, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *J. Spacecraft Rockets*, Vol. 4, No. 5, pp. 578–582, May 1967.

Kliore, A., "Radio Occultation Measurements of the Atmospheres of Mars and Venus," in *The Atmospheres of Venus and Mars*, edited by J. C. Brandt and M. B. McElrow, p. 205, Gordon and Breach Science Publishers, Inc., New York, N.Y., 1968.

Kliore, A. J., et al., "Summary of Mariner 6 and 7 Radio Occultation Results on the Atmosphere of Mars," *Space Research*, Vol. XI, pp. 165–175, Akademie-Verlag, Berlin, 1971.

Kliore, A. J., et al., "Mariner 9 S-Band Martian Occultation Experiment: Initial Results on the Atmosphere and Topography of Mars," *Science*, Vol. 175, No. 4019, pp. 313–317, Jan. 1972.

Labrum, R. G., et al., *The Surveyor V, VI, and VII Flight Paths and Their Determination from Tracking Data*, Technical Report 32-1302, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 1, 1968.

Laeser, R. P., et al., *Tracking and Data System Support for the Mariner Mars 1971 Mission: Prelaunch Phase Through First Trajectory Correction Maneuver*, Technical Memorandum 33-523, Vol. I, Jet Propulsion Laboratory, Pasadena, Calif., Mar. 15, 1972.

Layland, J. W., "On Optimal Signals for Phase-Locked Loops," *IEEE Trans. Commun. Technol.*, Vol. COM-17, No. 5, pp. 526–531, Oct. 1969.

Layland, J. W., and Lushbaugh, W. A., "A Flexible High-Speed Sequential Decoder for Deep Space Channels," *IEEE Trans. Commun. Technol.*, Vol. COM-19 No. 5, pp. 813–820, Oct. 1971.

Leavitt, R. K., *The Least-Squares Process of MEDIA for Computing DRVID Calibration Polynomials*, Technical Memorandum 33-542, Jet Propulsion Laboratory, Pasadena, Calif., May 15, 1972.

Levy, G. S., Otoshi, T. Y., and Seidel, B. L., *Ground Instrumentation for Mariner IV Occultation Experiment*, Technical Report 32-984, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 15, 1966.

Levy, G. S., et al., *Lunar Range Radiation Patterns of a 210-Foot Antenna at S-Band*, Technical Report 32-1079, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Trans. Antennas Propagation*, Vol. AP-15, No. 2, pp. 311–313, Mar. 1967.

Levy, G. S., et al., *The Ultra Cone: An Ultra-Low-Noise Space Communication Ground Radio-Frequency System*, Technical Report 32-1340, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Trans. Microwave Theor. Tech.*, Vol. MTT-16, No. 9, pp. 596–602, Sept. 1968.

Levy, G. S., et al., "Pioneer 6: Measurement of Transient Faraday Rotation Phenomena Observed During Solar Occultation," *Science*, Vol. 166, No. 3905, pp. 596–598, Oct. 1969.

Lieske, J. H., and Null, G. W., "Icarus and the Determination of Astronomical Constants," *Astron. J.*, Vol. 74, No. 2, Mar. 1969.

Lieske, J. H., et al., "Simultaneous Solution for the Masses of the Principal Planets from Analysis of Optical Radar and Radio Tracking Data," *Celest. Mech.*, Vol. 4, No. 2, pp. 233–245, Oct. 1971.

Lindsey, W. C., *Optimum and Suboptimum Frequency Demodulation*, Technical Report 32-637, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1964.

Lindsey, W. C., *Improvements to be Realized Through the Use of Block-Coded Communication Systems*, Technical Report 32-947, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Trans. Aerosp. Electron. Syst.*, Vol. AES-2, No. 3, pp. 364–366, May 1966.

Lindsey, W. C., *Phase-Shift-Keyed Signal Detection with Noisy Reference Signals*, Technical Report 32-968, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Trans. Aerosp. Electron. Syst.*, Vol. AES-2, No. 4, pp. 393–401, July 1966.

Lindsey, W. C., *A Theory for the Design of One-Way and Two-Way Phase-Coherent Communication Systems: Phase-Coherent Tracking Systems*, Technical Report 32-986, Jet Propulsion Laboratory, Pasadena, Calif., July 15, 1969.

Lindsey, W. C., *Optimal Design of One-Way and Two-Way Coherent Communication Links*, Technical Report 32-988, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Trans. Commun. Technol.*, Vol. COM-14, No. 4, pp. 418–431, Aug. 1966.

Lindsey, W. C., and Charles, F. J., *A Model Distribution for the Phase Error in Second-Order Phase-Locked Loops*, Technical Report 32-1017, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Trans. Commun. Technol.*, Vol. COM-14, No. 10, pp. 662–664, Oct. 1966.

Lindsey, W. C., *Performance of Phase-Coherent Receivers Preceded by Bandpass Limiters*, Technical Report 32-1162, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 15, 1967.

Lindsey, W. C., "Block Coding for Space Communications," *IEEE Trans. Commun. Technol.*, Vol. COM-17, No. 2, pp. 217–225, Apr. 1969.

Lindsey, W. C., *Block-Coded Communications*, Technical Report 32-1380, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 15, 1969.

Lindsey, W. C., *Nonlinear Analysis of Generalized Tracking Systems*, Technical Report 32-1453, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *Proc. IEEE*, Vol. 57, No. 10, pp. 1705–1722, Oct. 1969.

Lindsey, W. C., and Simon, M. K., "The Effect of Loop Stress on the Performance of Phase-Coherent Communication Systems", *IEEE Trans. Commun. Technol.*, Vol. COM-18, No. 5, pp. 569–588, Oct. 1970.

Lindsey, W. C., and Simon, M. K., "Carrier Synchronization and Detection of Polyphase Signals," *IEEE Trans. Commun.*, Vol. COM-20, No. 3, pp. 441–454, June 1972.

Lindsey, W. C., *Synchronization Systems in Communication and Control*, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1972.

Lindsey, W. C., and Simon, M. K., *Telecommunication Systems Engineering*, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1973.

Lorell, J., Anderson, J. D., and Sjogren, W. L., *Characteristics and Format of the Tracking Data to Be Obtained by the NASA Deep Space Instrumentation Facility for Lunar Orbiter*, Technical Memorandum 33-230, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1965.

Lorell, J., Sjogren, W. L., and Boggs, D., *Compressed Tracking Data Used for First Iteration in Selenodesy Experiment, Lunar Orbiters I and II*, Technical Memorandum 33-343, Jet Propulsion Laboratory, Pasadena, Calif., May 1, 1967.

Lorell, J., and Sjogren, W. L., *Lunar Orbiter Data Analysis*, Technical Report 32-1220, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 15, 1967.

Lorell, J., *Lunar Orbiter Gravity Analysis*, Technical Report 32-1387, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1969.

Lorell, J., et al., "Icarus: Celestial Mechanics Experiment for Mariner," *Int. J. Sol. Sys.*, Vol. 12, Jan. 1970.

Lorell, J., and Laing, P. A., *Compilation of Lunar Orbiter Tracking Data Used for Long-Term Selenodesy*, Technical Memorandum 33-419, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 1, 1970.

Ludwig, A. C., et al., *Gain Calibration of a Horn Antenna Using Pattern Integration*, Technical Report 32-1572, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 1, 1972.

Madrid, G. A., et al., *Tracking System Analytic Calibration Activities for the Mariner Mars 1971 Mission*, Technical Report 32-1587, Jet Propulsion Laboratory, Pasadena, Calif., Mar. 1, 1974.

Martin, D. P., *A Combined Radar-Radiometer With Variable Polarization*, Technical Memorandum 33-570, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 15, 1972.

McEliece, R. J., *Optimal Communications Nets*, Technical Report 32-697, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1965.

McNeal, C. E., *Ranger V Tracking Systems Data Analysis Final Report*, Technical Report 32-702, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1965.

Melbourne, W. G., et al., *Constants and Related Information for Astrodynamical Calculations*, Technical Report 32-1306, Jet Propulsion Laboratory, Pasadena, Calif., July 15, 1968.

Melbourne, W. G., "Planetary Ephemerides," *Astronaut. Aeronaut.*, Vol. 7, No. 5, pp. 38–43, May 1970.

Merrick, W. D., et al., *Deep Space Communications*, Technical Release 34-10, Jet Propulsion Laboratory, Pasadena, Calif., Jan. 29, 1960; also available in *IRE Trans. Mil. Electron.*, Vol. MIL-4, No. 2-3, pp. 158–163, April–June 1960.

Miller, L., et al., *The Atlas-Centaur VI Flight Path and Its Determination from Tracking Data*, Technical Report 32-911, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1966.

Moyer, T. D., *Mathematical Formulation of the Double-Precision Orbit Determination Program (DPODP)*, Technical Report 32-1527, Jet Propulsion Laboratory, Pasadena, Calif., May 17, 1971.

Muhleman, D. O., *Relationship Between the System of Astronomical Constants and the Radar Determinations of the Astronomical Unit*, Technical Report 32-477, Jet Propulsion Laboratory, Pasadena, Calif., Jan. 15, 1964.

Muhleman, D. O., Goldstein, R., and Carpenter, R., *A Review of Radar Astronomy—Parts I, II*, Technical Report 32-824, Jet Propulsion Laboratory, Pasadena, Calif., Jan. 30, 1966, reprinted from *IEEE Spectrum*, Oct. and Nov. 1965.

Muhleman, D. O., et al., *JPL Radar Range and Doppler Observations of Venus, 1961–1966*, Technical Report 32-1123, Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1968.

Mulhall, B. D., et al., *Tracking System Analytic Calibration Activities for the Mariner Mars 1969 Mission*, Technical Report 32-1499, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 15, 1970.

Mulholland, J. D., and Sjogren, W. L., *Lunar Orbiter Ranging Data*, Technical Report 32-1087, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *Science*, Vol. 155, No. 3758, pp. 74–76, Jan. 6, 1967.

Mulholland, J. D., *Proceedings of the Symposium on Observation, Analysis and Space Research Applications of the Lunar Motion*, Technical Report 32-1386, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 1969.

Muller, P. M., and Sjogren, W. L., *Consistency of Lunar Orbiter Residuals With Trajectory and Local Gravity Effects*, Technical Report 32-1307, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1968.

Muller, P. M., and Sjogren, W. L., *Mascons: Lunar Mass Concentrations*, Technical Report 32-1339, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *Science*, Vol. 161, No. 3842, pp. 680–684, Aug. 16, 1968.

Newburn, R. L., Jr., et al., *Earth-Based Research on the Outer Planets During the Period 1970–1985*, Technical Report 32-1456, Jet Propulsion Laboratory, Pasadena, Calif., Mar. 15, 1970.

Null, G. W., et al., *Mariner IV Flight Path and Its Determination From Tracking Data*, Technical Report 32-1108, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 1, 1967.

O'Neil, W. J., et al., *The Surveyor III and Surveyor IV Flight Paths and Their Determination From Tracking Data*, Technical Report 32-1292, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 15, 1968.

O'Neil, W. J., et al., *Mariner 9 Navigation*, Technical Report 32-1586, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 13, 1973.

Otoshi, T. Y., *The Effect of Mismatched Components on Microwave Noise-Temperature Calibrations*, Technical Report 32-1345, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Trans. Microwave Theor. Tech.*, Vol. MTT-16, No. 9, pp. 675–686, Sept. 1968.

Otoshi, T. Y., Stelzried, C. T., and Yates, B. C., "Comparisons of Waveguide Losses Calibrated by the DC Potentiometer, AC Ratio Transformer, and Reflectometer Techniques," *IEEE Trans. Microwave Theor. Tech.*, Vol. MTT-18, No. 7, pp. 406–409, July 1970.

Otoshi, T. Y., and Stelzried, C. T., "A Precision Compact Rotary Vane Attenuator," *IEEE Trans. Micro. Theor. Technique*, Vol. MTT-19, No. 11, pp. 843–854, Nov. 1971.

Pease, G. E., et al., *The Mariner V Flight Path and Its Determination From Tracking Data*, Technical Report 32-1363, Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1969.

Posner, E. C., *Properties of Error-Correcting Codes at Low Signal-to-Noise Ratios*, Technical Report 32-602, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1964.

Potter, P. D., *The Design of a Very High Power, Very Low Noise Cassegrain Feed System for a Planetary Radar*, Technical Report 32-653, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 24, 1964.

Potter, P. D., Merrick, W. D., and Ludwig, A. C., *Large Antenna Apertures and Arrays for Deep Space Communications*, Technical Report 32-848, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 1, 1965.

Potter, P. D., *A Computer Program for Machine Design of Cassegrain Feed Systems*, Technical Report 32-1202, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1967.

Potter, P. D., et al., *A Study of Weather-Dependent Data Links for Deep Space Applications*, Technical Report 32-1392, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 15, 1969.

Rechtin, E., "Communication Techniques for Space Exploration," *IRE Trans. Space Electron. Telem.*, Vol. SET-5, No. 3, pp. 95–98, Sept. 1959.

Rechtin, E., Stevens, R., and Victor, W. K., *Data Transmission and Communications*, Technical Release 34-55, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 30, 1960.

Rechtin, E., *Space Communications*, Technical Release 34-68, Jet Propulsion Laboratory, Pasadena, Calif., May 1, 1960.

Rechtin, E., Rule, B., and Stevens, R., *Large Ground Antennas*, Technical Report 32-213, Jet Propulsion Laboratory, Pasadena, Calif., Mar. 20, 1962.

Rechtin, E., *Lunar Communications*, Technical Memorandum 33-133, Jet Propulsion Laboratory, Pasadena, Calif., June 28, 1963.

Rechtin, E., "Surprises on Venus," *Int. Sci. Technol.*, No. 20, pp. 13–14, Aug. 1963

Renzetti, N. A., et al., "Radio Tracking Techniques and Performance of the U.S. Deep Space Instrumentation Facility," *Space Research II, Proceedings of the Second International Space Science Symposium*, Florence, Italy, April 1961, North Holland Publishing Company, Amsterdam.

Renzetti, N. A., and Ostermier, B. J., *Communications with Lunar Probes,* Technical Report 32-148, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 23, 1961.

Renzetti, N. A., *Tracking and Data Acquisition for Ranger Missions I–V,* Technical Memorandum 33-174, Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1964.

Renzetti, N. A., *Tracking and Data Acquisition for Ranger Missions VI–IX,* Technical Memorandum 33-275, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 15, 1966.

Renzetti, N. A., *Tracking and Data Acquisition Support for the Mariner Venus 1962 Mission,* Technical Memorandum 33-212, Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1965.

Renzetti, N. A., *Tracking and Data Acquisition Report, Mariner Mars 1964 Mission: Near-Earth Trajectory Phase,* Technical Memorandum 33-239, Vol. I, Jet Propulsion Laboratory, Pasadena, Calif., Jan. 1, 1965.

Renzetti, N. A., *Tracking and Data Acquisition Report, Mariner Mars 1964 Mission: Cruise to Post-Encounter Phase,* Technical Memorandum 33-239, Vol. II, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 1, 1967.

Renzetti, N. A., *Deep Space Network Support, Atlas/Centaur Missions 1–9,* Technical Memorandum 33-347, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 15, 1967.

Renzetti, N. A., "Tracking and Data Acquisition System for Mariner Missions," *Proceedings of the Seventh International Symposium on Space Technology and Science,* Tokyo, 1967.

Renzetti, N. A., *Tracking and Data Acquisition Report, Mariner Mars 1964 Mission: Extended Mission,* Technical Memorandum 33-239, Vol. III, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 1, 1968.

Renzetti, N. A., and Fearey, J. P., "The Deep Space Network: An Instrument for the Radio Navigation for the Mariner Mission to Mars 1969," IInd International Conference on Space Engineering, Venice, Italy, D. Reidel Publishing Co., Dordrecht, Holland, May 1969.

Renzetti, N. A., *Tracking and Data System Support for Surveyor: Missions I and II,* Technical Memorandum 33-301, Vol. I, Jet Propulsion Laboratory, Pasadena, Calif., July 15, 1969.

Renzetti, N. A., *Tracking and Data System Support for Surveyor: Missions III and IV,* Technical Memorandum 33-301, Vol. II, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1969.

Renzetti, N. A., *Tracking and Data System Support for Surveyor: Mission V,* Technical Memorandum 33-301, Vol. III, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 1, 1969.

Renzetti, N. A., *Tracking and Data System Support for Surveyor: Mission VI,* Technical Memorandum 33-301, Vol. IV, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 1, 1969.

Renzetti, N. A., *Tracking and Data System Support for Surveyor: Mission VII,* Technical Memorandum 33-301, Vol. V, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 1, 1969.

Renzetti, N. A., *Tracking and Data System Support for the Mariner Venus 67 Mission: Planning Phase Through Midcourse Maneuver*, Technical Memorandum 33-385, Vol. I, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1969.

Renzetti, N. A., *Tracking and Data System Support for the Mariner Venus 67 Mission: Midcourse Maneuver Through End of Mission*, Technical Memorandum 33-385, Vol. II, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1969.

Renzetti, N. A., *Tracking and Data System Support for the Pioneer Project: Pioneer VI. Prelaunch to End of Nominal Mission*, Technical Memorandum 33-426, Vol. I, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 1, 1970.

Renzetti, N. A., *Tracking and Data System Support for the Pioneer Project: Pioneer VII. Prelaunch to End of Nominal Mission*, Technical Memorandum 33-426, Vol. II, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1970.

Renzetti, N. A., *Tracking and Data System Support for the Pioneer Project: Pioneer VIII. Prelaunch Through May 1968*, Technical Memorandum 33-426, Vol. III, Jet Propulsion Laboratory, Pasadena, Calif., July 15, 1970.

Renzetti, N. A., *Tracking and Data System Support for the Pioneer Project: Pioneer IX. Prelaunch Through June 1969*, Technical Memorandum 33-426, Vol. IV, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 15, 1970.

Renzetti, N. A., *Tracking and Data System Support for the Pioneer Project: Pioneer VI. Extended Mission: July 1, 1966–July 1, 1969*, Technical Memorandum 33-426, Vol. V, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 1, 1971.

Renzetti, N. A., *Tracking and Data System Support for the Pioneer Project: Pioneer VII. Extended Mission: February 24, 1967–July 1, 1968*, Technical Memorandum 33-426, Vol. VI, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1971.

Renzetti, N. A., *Tracking and Data System Support for the Pioneer Project: Pioneer VII. Extended Mission: July 1, 1968–July 1, 1969*, Technical Memorandum 33-426, Vol. VII, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1971.

Renzetti, N. A., *Tracking and Data System Support for the Pioneer Project: Pioneer VIII. Extended Mission: June 1, 1968–July 1, 1969*, Technical Memorandum 33-426, Vol. VIII, Jet Propulsion Laboratory, Pasadena, Calif., May 1, 1971.

Renzetti, N. A., *Tracking and Data System Support for the Pioneer Project: Pioneers VI–IX. Extended Missions: July 1, 1969–July 1, 1970*, Technical Memorandum 33-426, Vol. IX, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 15, 1971.

Renzetti, N. A., and Siegmeth, A. J., *Tracking and Data System Support for the Pioneer Project: Pioneers 6–9. Extended Missions: July 1, 1971–July 1, 1972*, Technical Memorandum 33-426, Vol. XI, Jet Propulsion Laboratory, Pasadena, Calif., May 1, 1973.

Renzetti, N. A., et al., *Tracking and Data System Support for the Mariner Mars 1969 Mission: Planning Phase Through Midcourse Maneuver*, Technical Memorandum 33-474, Vol. I, Jet Propulsion Laboratory, Pasadena, Calif., May 15, 1971.

Renzetti, N. A., et al., *Tracking and Data System Support for the Mariner Mars 1969 Mission: Midcourse Maneuver Through End of Nominal Mission*, Technical Memorandum 33-474, Vol. II, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1971.

Renzetti, N. A., Linnes, K. W., and Taylor, T. M., *Tracking and Data System Support for the Mariner Mars 1969 Mission: Extended Operations Mission*, Technical Memorandum 33-474, Vol. III, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 15, 1971.

Renzetti, N. A., *A History of the Deep Space Network: From Inception to January 1, 1969*, Technical Report 32-1533, Vol. I, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1971.

Renzetti, N. A., "Radio Communications at Planetary Distances," paper presented at the International Convention on Radio Communication, Rome and Bologna, Italy, Mar. 1974.

Richter, H. L., Rechtin, E., and Walter, W. K., *National Ground-Based Surveillance Complex (U)*, Publication 146, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 16, 1959 (Confidential).

Rusch, W. V. T., *Phase Error and Associated Cross-Polarization Effects in Cassegrainian-Fed Microwave Antennas*, Technical Report 32-610, Jet Propulsion Laboratory, Pasadena, Calif., May 30, 1965.

Rusch, W. V. T., and Stelzried, C. T., *Observations of the Lunar Eclipse of December 19, 1964, at a Wavelength of 3.3 MM*, Technical Report 32-1097, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *Astrophys. J.*, Vol. 148, No. 1, pp. 255–259, Apr. 1967.

Rusch, W. V. T., *Applications of Two-Dimensional Integral-Equation Theory to Reflector-Antenna Analysis*, Technical Memorandum 33-478, Jet Propulsion Laboratory, Pasadena, Calif., May 1, 1971.

Sanger, D. K., *Digital Demodulation with Data Subcarrier Tracking*, Technical Report 32-1314, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 1, 1968.

Siegmeth, A. J., Purdue, R. E., and Ryan, R. E., *Tracking and Data System Support for the Pioneer Project: Pioneers 6–9. Extended Missions: July 1, 1970–July 1, 1971*, Technical Memorandum 33-426, Vol. X, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 15, 1972.

Siegmeth, A. J., et al., *Tracking and Data System Support for the Pioneer Project: Pioneer 10—Prelaunch Planning Through Second Trajectory Correction December 4, 1969 to April 1, 1972*, Technical Memorandum 33-584, Vol. I, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 1, 1973.

Simon, M. K., "Nonlinear Analysis of an Absolute Value Type of an Early-Late Gate Bit Synchronizer," *IEEE Trans. Commun. Technol.*, Vol. COM-18, No. 5, pp. 589-596, Oct. 1970.

Simon, M. K., "Optimization of the Performance of a Digital-Data-Transition Tracking Loop," *IEEE Trans. Commun. Technol.*, Vol. COM-18, No. 5, pp. 686–689, Oct. 1970.

Simon, M. K., and Lindsey, W. C., "Data-Aided Carrier Tracking Loops," *IEEE Trans. Commun. Technol.*, Vol. COM-19, No. 2, pp. 157–168, Apr. 1971.

Simon, M. K., "On the Selection of an Optimum Design Point for Phase-Coherent Receivers Employing Bandpass Limiters," *IEEE Trans. Commun.*, Vol. COM-20, No. 2, pp. 210–214, Apr. 1972.

Simon, M. K., "On the Selection of a Sampling Filter Bandwidth for a Digital Data Detector," *IEEE Trans. Commun.*, Vol. COM-20, No. 3, pp. 438–441, June 1972.

Sjogren, W. L., et al., *The Ranger V Flight Path and Its Determination From Tracking Data*, Technical Report 32-562, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 6, 1963.

Sjogren, W. L., et al., *The Ranger VI Flight Path and Its Determination From Tracking Data*, Technical Report 32-605, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1964.

Sjogren, W. L., *The Ranger III Flight Path and Its Determination From Tracking Data*, Technical Report 32-563, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 15, 1965.

Sjogren, W. L., et al., *Physical Constants as Determined From Radio Tracking of the Ranger Lunar Probes*, Technical Report 32-1057, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 30, 1966.

Sjogren, W. L., *Proceedings of the JPL Seminar on Uncertainties in the Lunar Ephemeris*, Technical Report 32-1247, Jet Propulsion Laboratory, Pasadena, Calif., May 1, 1968.

Sjogren, W. L., "Lunar Gravity Estimate: Independent Confirmation," *J. Geophys. Res.*, Vol. 76, No. 29, Oct. 10, 1971.

Sjogren, W. L., et al., "Lunar Gravity via Apollo 14 Doppler Radio Tracking," *Science*, Vol. 175, No. 4018, pp. 165–168, Jan. 14, 1972.

Slobin, S. D., "Beam Switching Cassegrain Feed System and Its Applications to Microwave and Millimeterwave Radioastronomical Observations," *Rev. Sci. Instr.*, Vol. 41, No. 3, pp. 439–443, Mar. 1970.

Spier, G. W., *Design and Implementation of Models for the Double Precision Trajectory Program (DPTRAJ)*, Technical Memorandum 33-451, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1971.

Springett, J. C., and Simon, M. K., "An Analysis of the Phase Coherent-Incoherent Output of the Bandpass Limiter," *IEEE Trans. Commun. Technol.*, Vol. COM-19, No. 1, pp. 42–49, Feb. 1971.

Stelzried, C. T., *Post-Amplifier Noise Temperature Contribution in a Low-Noise Receiving System*, Technical Report 32-446, Jet Propulsion Laboratory, Pasadena, Calif., Jan. 1964.

Stelzried, C. T., Reid, M. S., and Petty, S. M., *A Precision DC-Potentiometer Microwave Insertion-Loss Test Set*, Technical Report 32-887, Jet Propulsion Laboratory, Pasadena, Calif., Mar. 15, 1966.

Stelzried, C. T., Reid, M. S., and Nixon, D., *Precision Power Measurements of Spacecraft CW Signal With Microwave Noise Standards*, Technical Report 32-1066, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 15, 1968.

Stelzried, C. T., and Reid, M. S., *Precision Power Measurements of Spacecraft CW Signal Level With Microwave Noise Standards*, Technical Report 32-1070, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Trans. Instrum. Measurement*, Vol. IM-15, No. 4, pp. 318–324, Dec. 1966.

Stelzried, C. T., and Rusch, W. V. T., *Improved Determination of Atmospheric Opacity From Radio Astronomy Measurements*, Technical Report 32-1115, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *J. Geophys. Res.*, Vol. 72, No. 9, pp. 2445–2447, May 1, 1967.

Stelzried, C. T., and Otoshi, T. Y., "Radiometric Evaluation of Antenna-Feed Component Losses," *IEEE Trans. Instrumen. Measurement*, Vol. IM-18, No. 3, pp. 172–183, Sept. 1969.

Stelzried, C. T., "Precision Microwave Waveguide Loss Calibrations," *IEEE Trans. Instrum. Measurement*, Vol. IM-19, No. 1, pp. 23–25, Feb. 1970.

Stelzried, C. T., *A Faraday Rotation Measurement of a 13-cm Signal in the Solar Corona*, Technical Report 32-1401, Jet Propulsion Laboratory, Pasadena, Calif., July 15, 1970.

Stelzried, C. T., et al., "The Quasi-Stationary Coronal Magnetic Field and Electron Density as Determined From a Faraday Rotation Experiment," *Sol. Phys.*, Vol. 14, No. 2, pp. 440–456, Oct. 1970.

Stelzried, C. T., "Operating Noise-Temperature Calibrations of Low-Noise Receiving Systems," *Microwave J.*, Vol. 14, No. 6, pp. 41–46, 48, June 1971.

Stelzried, C. T., et al., "Transformation of Received Signal Polarization Angle to the Plane of the Ecliptic," *J. Space. Rock.*, Vol. 9, No. 2, pp. 69–70, Feb. 1972.

System Capabilities and Development Schedule of the Deep Space Instrumentation Facility 1963–1967, Technical Memorandum 33-83, Jet Propulsion Laboratory, Pasadena, Calif., Mar. 2, 1962.

Tardani, P. A., *Madrid Site Selection Report*, Technical Memorandum 33-149, Jet Propulsion Laboratory, Pasadena, Calif., July 17, 1963.

Tausworthe, R. C., *A Precision Planetary Range-Tracking Radar*, Technical Report 32-779, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Trans. Space Electron. Telem.*, Vol. SET-11, No. 2, pp. 78–85, June 1965.

Tausworthe, R. C., *Theory and Practical Design of Phase-Locked Receivers*, Technical Report 32-819, Vol. I, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 15, 1966.

Tausworthe, R., *Cycle Slipping in Phase-Locked Loops*, Technical Report 32-1127, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Trans. Commun. Technol.*, Vol. COM-15, No. 3, pp. 417–421, June 1967.

Tausworthe, R. C., Easterling, M. F., and Spear, A. J., *A High-Rate Telemetry System for the Mariner Mars 1969 Mission*, Technical Report 32-1354, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 1, 1969.

Tausworthe, R. C., *DSS Subsystem Implementation by Time-Shared Computer*, Technical Memorandum 33-420, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 1, 1969.

Tausworthe, R. C., "Convergence of Oscillator Spectral Estimators for Counted-Frequency Measurements," *IEEE Trans. Commun.*, Vol. COM-20, No. 2, pp. 213–217, Apr. 1972.

Tausworthe, R. C., "Simplified Formula for Mean-Slip Time of Phase-Locked Loops With Steady-State Phase Error," *IEEE Trans. Commun.*, Vol. COM-20, No. 3, pp. 331–337, June 1972.

Telecommunications Systems Design Techniques Handbook, Technical Memorandum 33-571, edited by R. E. Edelson, Jet Propulsion Laboratory, Pasadena, Calif., July 15, 1972.

Textor, G. P., Kelly, L. B., and Kelly, M., *Tracking and Data System Support for the Mariner Mars 1971 Mission: First Trajectory Correction Maneuver Through Orbit Insertion*, Technical Memorandum 33-523, Vol. II, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1972.

Thornton, J. H., Jr., *The Surveyor I and Surveyor II Flight Paths and Their Determination From Tracking Data*, Technical Report 32-1285, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 1, 1968.

Timor, U., "Equivalence of Time-Multiplexed and Frequency-Multiplexed Signals in Digital Communications," *IEEE Trans. Commun.*, Vol. COM-20, No. 3, pp. 435–438, June 1972.

Titsworth, R. C., and Welch, L. R., *Power Spectra of Signals Modulated by Random and Pseudorandom Sequences*, Technical Report 32-140, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 10, 1961.

Titsworth, R. C., *The Algebra of Periodic Sequences*, Technical Report 32-381, Jet Propulsion Laboratory, Pasadena, Calif., Jan. 7, 1963.

Titsworth, R. C., *Correlation Properties of Cyclic Sequences*, Technical Report 32-388, Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1963.

Titsworth, R. C., *Optimal Ranging Codes*, Technical Report 32-411, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1963.

Titsworth, R. C., *Equivalence Classes of Periodic Sequences*, Technical Report 32-568, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1964, reprinted from *Ill. J. Math.*, Vol. 8, No. 2, June 1964.

Titsworth, R. C., *The Role of Pseudorandom Codes in Communications*, Technical Memorandum 33-185, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 3, 1964.

"Tracking and Data Acquisition System for Mariner Missions," *Proceedings of the Seventh International Symposium on Space Technology and Science*, Tokyo, May 1967.

Vegos, C. J., et al., *The Ranger IX Flight Path and Its Determination From Tracking Data*, Technical Report 32-767, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 1, 1968.

Victor, W. K., Stevens, R., and Golomb, S. W., *Radar Exploration of Venus: Goldstone Observatory Report for March-May 1961*, Technical Report 32-132, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 1, 1961.

Victor, W. K., Titsworth, R. C., and Rechtin, E., *Telecommunication Aspects of a Manned Mars Mission*, Technical Report 32-501, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 20, 1963.

Viterbi, A. J., *Acquisition Range and Tracking Behavior of Phase-Locked Loops*, External Publication 673, Jet Propulsion Laboratory, Pasadena, Calif., July 14, 1959.

Viterbi, A. J., *On Coded Phase-Coherent Communications*, Technical Report 32-25, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 15, 1960.

Viterbi, A. J., *Classification and Evaluation of Coherent Synchronous Sampled-Data Telemetry Systems*, Technical Report 32-123, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1961.

Viterbi, A. J., *Phase-Locked Loop Dynamics in the Presence of Noise by Fokker-Planck Techniques*, Technical Report 32-427, Jet Propulsion Laboratory, Pasadena, Calif., Mar. 29, 1963; also reprinted in *IEEE Proc.*, Vol. 51, No. 12, pp. 1737–1753, Dec. 1963.

Viterbi, A. J., *Orthogonal Tree Codes for Communication in the Presence of White Gaussian Noise*, Technical Report 32-1120, Jet Propulsion Laboratory, Pasadena, Calif., reprinted from *IEEE Trans. Commun. Technol.*, Vol. COM-15, No. 2, pp. 238–242, Apr. 1967.

Winn, F. B., "Selenographic Location of Surveyor VI," in *Surveyor VI Mission Report: Part II. Science Results*, Technical Report 32-1262, Jet Propulsion Laboratory, Pasadena, Calif., Jan. 10, 1968.

Winn, F. B., "Post Landing Tracking Data Analysis," in *Surveyor VII Mission Report: Part II. Science Results*, Technical Report 32-1264, Jet Propulsion Laboratory, Pasadena, Calif., Mar. 15, 1968.

Winn, F. B., "Surveyor Post-Touchdown Analysis of Tracking Data," in *Surveyor Project Final Report: Part II. Science Results*, Technical Report 32-1265, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1968.

Winn, F. B., *Surveyor Posttouchdown Analyses of Tracking Data*, NASA SP-184, National Aeronautics and Space Administration, Washington, D.C., p. 369.

Wollenhaupt, W. R., *Tracking System Data Analysis Report, Ranger 4 Final Report*, Technical Report 32-523, Jet Propulsion Laboratory, Pasadena, Calif., Mar. 1, 1964.

Wollenhaupt, W. R., et al., *The Ranger VII Flight Path and Its Determination From Tracking Data*, Technical Report 32-694, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1964.

DEFINITION OF ACRONYMS AND SYMBOLS

ACN	STDN station, Ascension Island
ACS	Attitude Control System
ADSS	Automatic Data Switching System
AFETR	Air Force Eastern Test Range
AGC	automatic gain control
ANT	Antigua
AOS	acquisition of signal
APS	Antenna Pointing Subsystem
ARC	Ames Research Center
ASC	Ascension
ASU	automatic switch unit
ATRS	Automatic Telemetry Recall System
BDA	Bermuda
BECO	booster engine cutoff
BER	bit error rate
CDC	Command and Data Handling Console
CERT	composite electrical readiness test
CIF	Central Instrumentation Facility
CKAFS	Cape Kennedy Air Force Station
CKE	Cape Kennedy
CLT	communications line terminal
CMA	Command Modulator Assembly
CNA	cone angle
CRO	Carnarvon
CTA	compatibility test area

Conscan	Conical Scan System
CMO	Chief of Mission Operations
CP	Communications Processor
CPS	Central Processing System
CTRVC	Corrected time required velocity correction
CY1	STDN station, Grand Canary Island (Spain)
DCU	digital computer unit
DIS	Digital Instrumentation Subsystem
DOY	Day of Year
DPTRAJ	Double Precision Trajectory Program
DRAM	discrete recorder and monitor
DSCC	Deep Space Communications Complex
DSIF	Deep Space Instrumentation Facility
DSN	Deep Space Network
DSS	Deep Space Station
EDR	Experiment Data Record
ELA	Earth look angle
EOM	end of mission
EOT	end of track
F	flight
FD	Flight Director
FED	flight events demonstration
FPAC	flight path analysis and computation
FTS	Frequency and Timing Subsystem
GBI	Grand Bahama Island
GCF	Ground Communications Facility

GDS	Ground Data System
GMT	Greenwich Mean Time
GOE	ground operations equipment
GPCF	General Purpose Computing Facility
GRTS	Goddard Real-Time System
GSE	ground support equipment
GSFC	Goddard Space Flight Center
GTK	Grand Turk
GTV	ground transport vehicle
HSD	high speed data
HSDL	high speed data line
ID	Identification
IRS	Information Retrieval System
IRV	Inter-range Vector
JPL	Jet Propulsion Laboratory
L	launch
LOS	loss of signal
LTDS	Launch Trajectory Data System
M	maneuver
MCCC	Mission Control and Computing Center
MCD	monitor criteria data
MDC	Mission Direction Center
MDE	mission dependent equipment
MDF	Master Data File
MDR	Master Data Record
MECO	main engine cutoff

MES	main engine start
MIL	Merritt Island S/C Compatibility Monitor Station
MMC	Multiple Mission Command
MMT	Multiple-Mission Telemetry
MOS	Mission Operations System
MRL	Maneuver Readiness Log
MSA	Mission Support Area
MSFN	Manned Space Flight Network
MUX Line	Multiplexed Communication Line
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications Network
NAA	Network Analysis Area
NAT	Network Analysis Team
NAV	navigation
NCS	Network Control System
NEP	near-Earth phase
NETDS	near-Earth TDS
NOCC	Network Operations Control Center
NOPE	Network Operations Project Engineer
NSP	NASA Support Plan
NTTF	Network Test and Training Facility
OC	Operations Chief
OCIS	Office of Computing and Information Systems
OCT	Operations Control Team
OD	orbit determination
ODC	Operational Data Control

ODR	Original Data Record
ORT	Operational Readiness Test
OSS	Office of Space Science
OTC	out of tolerance condition
OTDA	Office of Tracking and Data Acquisition
OVT	Operational Verification Test
PAT	Patrick Air Force Base
PCU	power control unit
PCUC	positive continuous ullage control
PDS	polarimeter diplexed S-band
PE	Project Engineer
PER	parity error rate
PET	probe ephemeris tapes
PMAA	Pioneer Mission Analysis Area
PMCCC	Pioneer Mission Control and Computer Center
PMOC	Pioneer Mission Operations Center
PMOPS	Pioneer Mission Operations
PMSA	Pioneer Mission Support Area
POGASIS	Planetary Orbiting Geometry and Scientific Simulation Computer Program
PPO	Pioneer Project Office
PRE	Pretoria
PSE	Pioneer Storage and Execution
PSK	phase-shift keying
PU	propellant utilization
RCA	radius of closest approach
RDIE	remote digital interface equipment

RIA	range instrumentation aircraft
RIC	Remote Information Center
RIS	Range Instrumentation Ship
R_j	Jupiter radius
RP1	rocket propellant 1
RSC	range safety control
RTCS	Real Time Computing System
RTG	radioisotope thermoelectric generator
RTLT	round-trip light time
SATODP	Satellite Tracking Orbit Determination Program
S/C	spacecraft
SCT	SFOF Communications Terminal
SCU	S-band Cassegrain Ultracone
SDA	Subcarrier Demodulator Assembly
SDCC	Simulation Data Conversion Center
SDL	System Development Laboratory
SDR	System Data Record
SECO	sustainer engine cutoff
SFOF	Space Flight Operations Facility
SFOP	Space Flight Operation Plan
SIRD	Support Instrumentation Requirements Document
SIMCEN	Simulation Center
SLA	Sun look angle
SMT	S-band megawatt transmit
SNR	signal-to-noise ratio
SNT	system noise temperature
SOE	sequence of events

SOPM	Standard Orbital Parameters Messages
SPU	S-band polarized ultracone
SSA	Symbol Synchronizer Assembly
STDN	Spaceflight Tracking and Data Network
STL	Space Technology Laboratory
STS	Satellite Tracking Station
SWCEN	Switching Center
T	time of event
TAN	STDN station, Tananarive, Malagasy Republic
TCD	Telemetry and Command Data Handling Subsystem
TCP	Telemetry and Command Processor
TDA	Tracking and Data Handling Subsystem
TDS	Tracking and Data System
TEL 4	AFETR main island telemetry station
TLM	telemetry
T_s	system temperature
TSP	test support position
TTY	teletype
TWT	traveling wave tube
UPS	Uninterruptible Power System
USB	unified S-band
VAN	Vanguard (Apollo Ship)
VCO	Voltage controlled oscillator
VOCA	Voice Operational Communications Assembly
YO	despin counterweight

NASA — JPL — Coml., L.A., Calif.