NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-450

Tracking and Data System Support for Lunar Orbiter

J. R. Hall

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

April 15, 1970

OVERLEAF: *The DSN initial acquisition station for the Lunar Orbiter Project at DSS 41, Woomera, Australia. The large Cassegrain feed in the center of the 85-ft diam dish provides the high-gain beam. The smaller square structure to the right of the cone is the acquisition aid antenna.*

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National Aeronautics and Space Administration

Preface

The work described in this report was performed by the tracking and data acquisition organizations of the Jet Propulsion Laboratory, Air Force Eastern Test Range, and the Manned Space Flight Network and NASA Communications Network of the Goddard Space Flight Center.

This volume is the final report of the Tracking and Data System support of the *Lunar Orbiter* Project of which Part I is a summary describing the Tracking and Data System support results and the methodology of planning, implementation, and flight support for the five *Lunar Orbiter* missions. The additional five Parts describe with greater detail the performance of the Deep Space Network in support of Missions I through V.

Acknowledgment

For his own part and for the *Lunar Orbiter* Tracking and Data System Manager, the author wishes to express gratitude to the many planning, implementation, and operational staff engineers of the several agencies comprising the *Lunar Orbiter* Tracking and Data System. Each has contributed his own technical and management skill and dedicated himself to a degree which has resulted in one of the most successful lunar exploration programs to date.

This report was prepared largely from the material contained in Jet Propulsion Laboratory internal reports and memoranda, and from publications of the Air Force Eastern Test Range and Goddard Space Flight Center NASCOM and MSFN functions. Special recognition is given the following contributors to this report:

J. Walker
P. Shupe
J. Brenkle
A. Sheppard
B. Deluca
F. Borncamp
J. Capps
W. Sjogren
H. Moss

The author wishes to acknowledge the contribution of Richard Chandlee for his efforts in researching and organizing much of the material contained in the final report.

For historical purposes the following TDS personnel who contributed directly to the *Lunar Orbiter* Project as project or line personnel are listed; the numbers in parentheses indicate successive appointments during the course of the Project:

TDS Manager — (1) M. S. Johnson, (2) J. W. Thatcher
DSN Manager — (1) M. S. Johnson, (2) J. R. Hall
DSIF Manager — R. Stevens
SFOF Manager — G. E. Lairmore
DSIF Operations Manager — R. K. Mallis
SFOF/GCF Operations Manager — (1) P. J. Rygh, (2) M. Rosenbluth
DSN Project Engineer — (1) J. Eyraud, (2) R. Rung, (3) J. Walker
TDS Flight Analyst — J. Reuyl, H. Moss
TDS Near Earth Project Engineer — P. Shupe
Software Integration Support — J. F. Scott
DSN FPAC Support — J. Brenkle, W. Sjogren
DSN Data Processing Project Engineer — (1) N. Newhall, (2) G. Orozco, (3) W. Schneider
DSIF Operations Engineer — A. S. Sheppard
DSIF Operations Planning — (1) G. K. Hornbrook, (2) B. Deluca
DSIF System Data Analysis — F. Borncamp, H. Palmiter

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GCF Project Engineer — J. W. Capps
SFOF Operations Support — R. A. Hall
SFOF Project Engineer — M. Stewart

Near Earth

W. Bradley (MSFN) H. H. Allen (AFETR)
F. C. Drury (KSC)

NASCOM

D. Schmittling

Space limitation prohibits the listing of many hundreds of individuals who provided valuable support on a part-time basis.

The author also wishes to acknowledge the significant contribution of M. E. Binkley and A. C. Belcher of the NASA Office of Tracking and Data Acquisition for their management efforts in obtaining support for this effort from the many NASA and other government agencies.

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Abstract

This volume contains a general summary of the *Lunar Orbiter* support including Tracking and Data System (TDS) accomplishments and management experience. *Lunar Orbiter* mission requirements placed on the TDS as well as the TDS requirements on the *Lunar Orbiter* Project are defined. The TDS configuration and test requirements are listed and a support summary by facility is provided. Finally, a description of the TDS support for each of the five missions is detailed.

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Part I. *Lunar Orbiter* Project Support

I. Introduction

A. Purpose of Report

This document describes and summarizes the organization and activities of the Tracking and Data System (TDS) in support of the *Lunar Orbiter* Project (LOP). It provides a management-level description of the structure, planning, implementation, and performance of the TDS during the five *Lunar Orbiter* missions. Particular emphasis has been given to the analyses of Deep Space Network (DSN) loading, data quality, and the percentage of data recovery for the *Lunar Orbiter* mission.

B. Organization and Scope

This document is divided into six parts and covers those activities and interfaces for which the TDS was responsible. Part I contains a general description of the TDS organization and a summary of its performance during the five *Lunar Orbiter* missions. A brief description of the *Lunar Orbiter* spacecraft and mission is included. Detailed support information on each of the five missions will be found in subsequent parts. Additional detailed information on project support requirements, the TDS configuration and detailed performance and analysis can be found in the Support Instrumentation Requirements Document (SIRD), the National Aeronautics and Space Administration (NASA) Support Plan (NSP), and other documents listed in the bibliography.

C. Tracking and Data Acquisition Function

The Tracking and Data Acquisition (TDA) function is defined as the acquisition, transmission, processing, display, and control of spacecraft tracking and communications information necessary to the support of flight project mission requirements. These project requirements include navigation, scientific measurements, photography, spacecraft and mission control, and spacecraft performance monitoring.

The Jet Propulsion Laboratory (JPL) was designated as the Tracking and Data Acquisition Support Center for the LOP by NASA Headquarters. As such, JPL was responsible for providing the TDA function. To implement this function, a Tracking and Data System Manager for the LOP was appointed by JPL in 1964. The TDA Manager was the interface manager between the LOP and the TDS support agencies, and was responsible for matching the requirements of the LOP with the capabilities of the support agencies. The resulting composite organization of supporting resources was identified as the *Lunar Orbiter* TDS.

During the course of the project, TDS support was separated into two standard support phases: the near-earth phase and the deep-space phase. The near-earth phase provided necessary support during the spacecraft launch phase. The deep-space phase provided the necessary support during the spacecraft cruise and orbital operations phase of the mission. The near-earth phase began with the launch countdown and normally ended when the spacecraft was in continuous view of the DSN tracking stations. The near-earth phase was primarily supported by the Air Force Eastern Test Range (AFETR) and the Manned Space Flight Network (MSFN) metric and TDA facilities, the AFETR computer system, the JPL–AFETR operations and communications center, and the Spacecraft Monitor Facility at DSS 71.[1] The deep space phase began when the spacecraft was in continuous view of the DSS of the DSN and continued through the end of the mission. The deep-space phase was supported entirely by the NASA DSN.

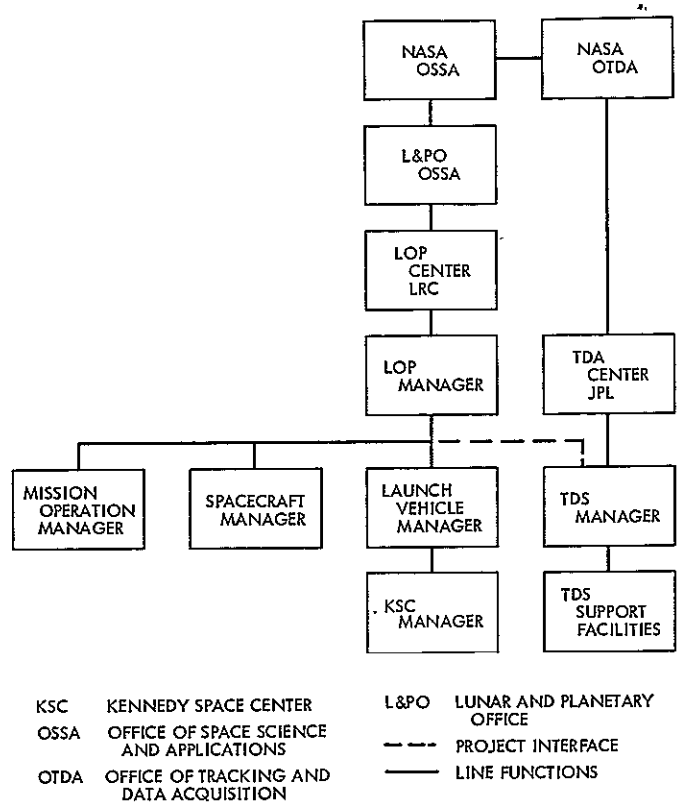

Fig. 1. The LOP–TDS organization

D. *Lunar Orbiter* Project Description

1. Project establishment and organization. The LOP was established in May 1964. The first launch opportunity was planned for May 1966. Management of the Project was assigned by NASA to Langley Research Center (LRC), Hampton, Virginia. The Boeing Company, Seattle, Washington, was selected as the prime contractor and given responsibility for the Spacecraft System, the Mission Operations System, and the Project integration function. The relationship of the Project and TDS organizations is shown in Fig. 1.

2. Mission objectives. The prime objectives of the LOP were to search for and survey acceptable lunar landing sites for the *Apollo* Project. Additional objectives to be accomplished after the prime objective were: (1) to obtain high-resolution 50-m photographs of a large percentage of the lunar topography, (2) to survey sites of special scientific interest, and (3) to obtain metric data for use in generating a precise model of the lunar gravitational field.

3. Spacecraft description. The *Lunar Orbiter* spacecraft was an attitude-stabilized vehicle using either gyro or sun-Canopus position references, and was actively oriented by cold-gas thrusters. The spacecraft weighed approximately 850 lb and measured 7 ft high, 17 ft across its maximum dimension, and 12 ft across the solar panels. The spacecraft in its flight configuration with all elements fully deployed is depicted in Fig. 2; the mylar thermal barrier which normally covered the central section of the spacecraft is not shown. Basic spacecraft electrical power was provided by sun-oriented solar panels. Batteries provided power during lunar occultation and orientation maneuvers.

The basic spacecraft payload was a precision camera and film processing system capable of high (1 m) and medium (10 m) resolution of lunar surface features when photographed from an altitude of 50 km above the lunar surface. The *Lunar Orbiter* camera film supply permitted approximately 250 photographs with a total information content of approximately 10^{13} bits. The pictures were exposed, developed, dried, scanned photoelectrically, and transmitted to earth. Radiation and micrometeorite detection instruments were also on board, and were used to support photographic experiment operations.

[1]DSS 71 is the Deep Space Station at Cape Kennedy, Florida. All DSS designations are identified in the Glossary at the end of this document.

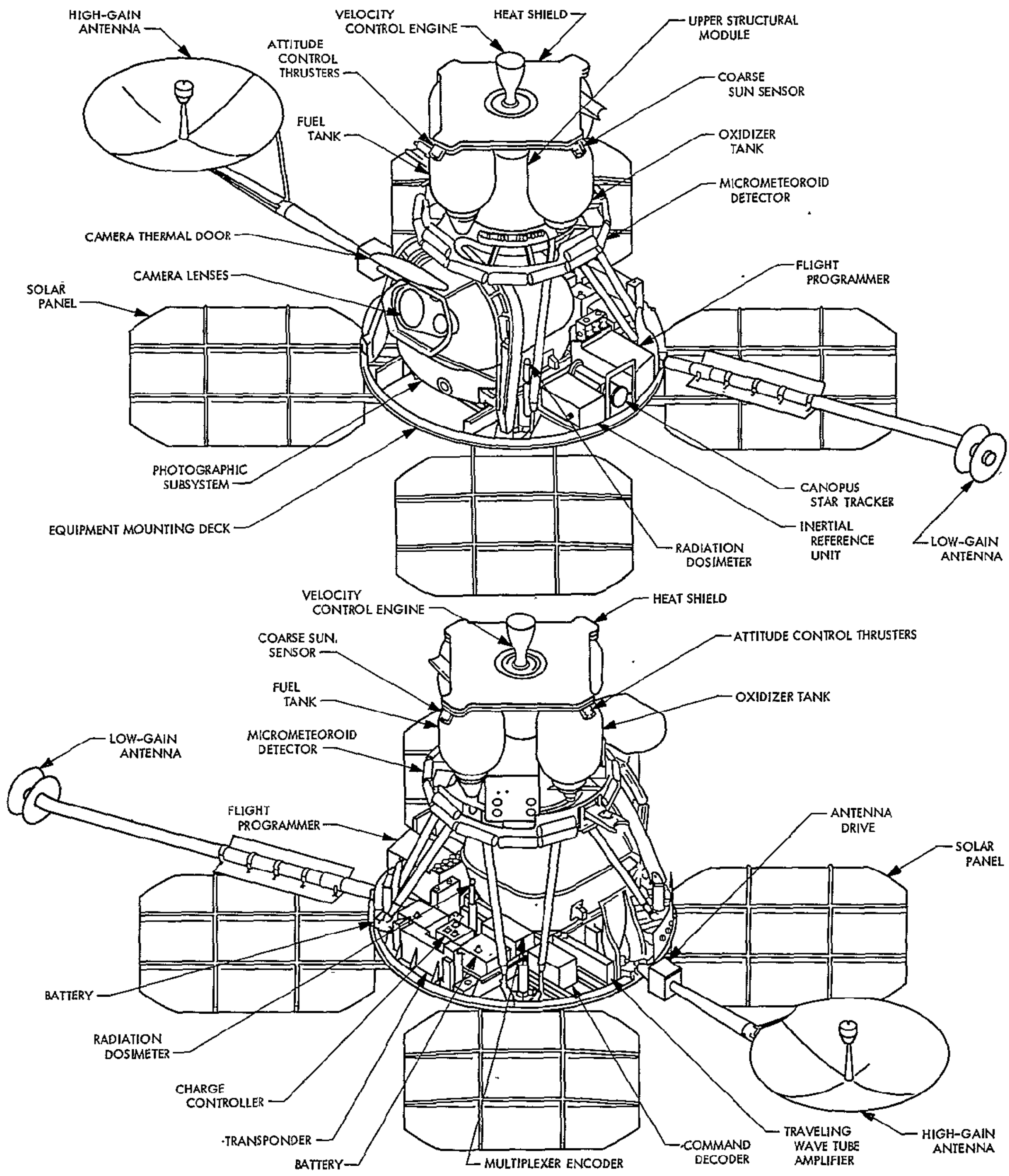

Fig. 2. *Lunar Orbiter* **spacecraft**

The spacecraft communications system consisted of a two-way coherent transponder with a "turnaround ranging" capability, and was compatible with the DSN Unified S-Band Tracking System. Commands and ranging modulation were transmitted on the uplink. Telemetry, video, and ranging modulation were transmitted on the downlink. The *Lunar Orbiter* Project was the first to successfully use the DSN Ranging Subsystem to provide ranging data as a metric data observable. The Ranging Subsystem was also used to provide time correlation measurements between Deep Space Instrumentation Facility (DSIF) tracking stations.

The spacecraft contained both omnidirectional and high-gain (25 dB) antennas for communication with the DSN. The spacecraft RF power output was 0.5 W when the omnidirectional antenna was used, and 10 W when the high-gain antenna was used. The video mode of the spacecraft normally required the use of the high-gain antenna and 10-W transmitter. The spacecraft video information modulated a 310 kHz subcarrier using a single sideband AM technique. The telemetry system operated at a constant bit rate of 50 bits/s and biphase modulated a 30 kHz subcarrier. The composite telemetry and video spectra then phase-modulated the RF carrier. The command system operated at a bit rate of 20 bits/s and used a frequency shift keying (FSK) modulation technique. The command system required the telemetry channel for real-time verification. The spacecraft was designed to operate without commands until well after solar acquisition. At this time the spacecraft was in continuous view of the DSN.

The spacecraft utilized a bipropellant propulsion system which provided the necessary impulse for midcourse correction, lunar orbit insertion, and lunar orbit trim maneuvers. The system consisted of a single 100-lbf rocket engine. Nitrogen tetroxide and aerozene were utilized as propellants.

4. Launch vehicle description. An *Atlas-Agena* launch vehicle combination was used for the *Lunar Orbiter* spacecraft mission. A parking orbit launch trajectory design was used with launch azimuths from 90 to 114 deg. The injection location was dependent on the month of launch, and varied from 15 deg north latitude to 30 deg south latitude. The typical launch window was approximately 3 h.

5. Mission profile. A pictorial summary of a typical *Lunar Orbiter* mission profile is shown in Fig. 3. Event times of major significance are shown from initiation of the countdown through the initial two-way acquisition by the DSN, and are given with respect to lift-off time. Each mission design was based upon requirements for placing the spacecraft over selected targets at the desired altitude, and within the established lighting limitations for quality photography. Selection of the lunar insertion trajectory parameters was dictated by the need to satisfy mission conditions, e.g., an earth-moon transit time of approximately 90 h, final lunar orbit periselenic and aposelenic altitudes, nominally 48 and 1500 km, respectively, the desired sun illumination band, and the initial periselenic location and locus.

E. Tracking and Data System Support

1. Support summary. The support provided to the *Lunar Orbiter* Project by the TDS met all mission requirements. The scope of the TDS effort included DSIF, Ground Communications Facility (GCF), and Space Flight Operations Facility (SFOF) support, compatibility testing, the training of Project operations personnel, and flight path analysis support. The following comments relate to some of the more significant accomplishments and experience gained by the TDS during the LOP.

2. TDS accomplishments. There were several accomplishments during the TDS support of the LOP; among these were:

(1) First use, along with the *Surveyor* Project, of the NASA Communications Network (NASCOM) high-speed data lines (2400 bits/s) for transmitting operational telemetry information in real time from the DSIF stations.

(2) First operational use of the DSN Ranging Subsystem, the ranging observable for orbit determination, and use of the Ranging Subsystem for DSS time synchronization.

(3) First TDS simultaneous support of several operational spacecraft for the same project. During one period, three *Lunar Orbiter* spacecraft were supported simultaneously while in lunar orbit.

(4) First experience with continuous, 24 h, intense operations activity which extended over a 30-day period during the photographic phase of each mission. The spacecraft were continually monitored, oriented, photo operations conducted, and navigation parameters determined, all in near-real time over this period.

NEAR-EARTH EVENTS

PRELAUNCH EVENTS

START COUNTDOWN	L - 8 h 30 min
SPACECRAFT PROGRAMMER LOADING	L - 7 h 25 min
AGENA PROPELLANT LOADING	L - 2 h 35 min
REMOVE GANTRY	L - 2 h 10 min
AGENA OXIDIZER LOADING	L - 1 h 30 min
BUILTIN 50-min HOLD	L - 1 h
BUILTIN 10-min HOLD	L - 0 h 7 min

LIFTOFF	L + 2 min 22 s
BOOSTER ENGINE CUTOFF(BECO)	L + 2 min 22 s
SUSTAINER ENGINE CUTOFF (SECO)	L + 4 min 40 s
VERNIER ENGINE CUTOFF (VECO)	L + 5 min 25 s
NOSE FAIRING SEPARATION	L + 5 min 10 s
ATLAS-AGENA SEPARATION	L + 5 min 12 s
AGENA FIRST IGNITION (INJECTION INTO EARTH ORBIT)	L + 6 min 10 s

LIFTOFF (CONTD)

AGENA CUTOFF (COAST IN EARTH ORBIT)	L + 8 min 43 s
AGENA SECOND IGNITION	L + 31 min 21 s
AGENA CUTOFF	L + 32 min 48 s
SPACECRAFT/AGENA SEPARATION (INJECTION)	L + 32 min 55 s
EXTEND ANTENNAS	L + 37 min 22 s
EXTEND SOLAR PANELS	L + 37 min 55 s
AGENA RETROFIRE	L + 45 min 33 s
START SUN ACQUISITION	L + 50 min
SUN ACQUISITION COMPLETE	L + 53 min

DEEP SPACE EVENTS

INITIAL SPACECRAFT ACQUISITION BY DSN	L + 53 min 12 s
FIRST DSIF STATION TRANSFER	L + 6 h 55 min
START CANOPUS ACQUISITION	L + 20 h 21 min
FIRST MIDCOURSE MANEUVER	L + 31 h 27 min
LUNAR ORBIT INJECTION	L + 90 h
FIRST PHOTO	L + 108 h
END OF PHOTOGRAPHY (BIMAT CLEAR)	L + 18 days
END OF FINAL READOUT	L + 27 days

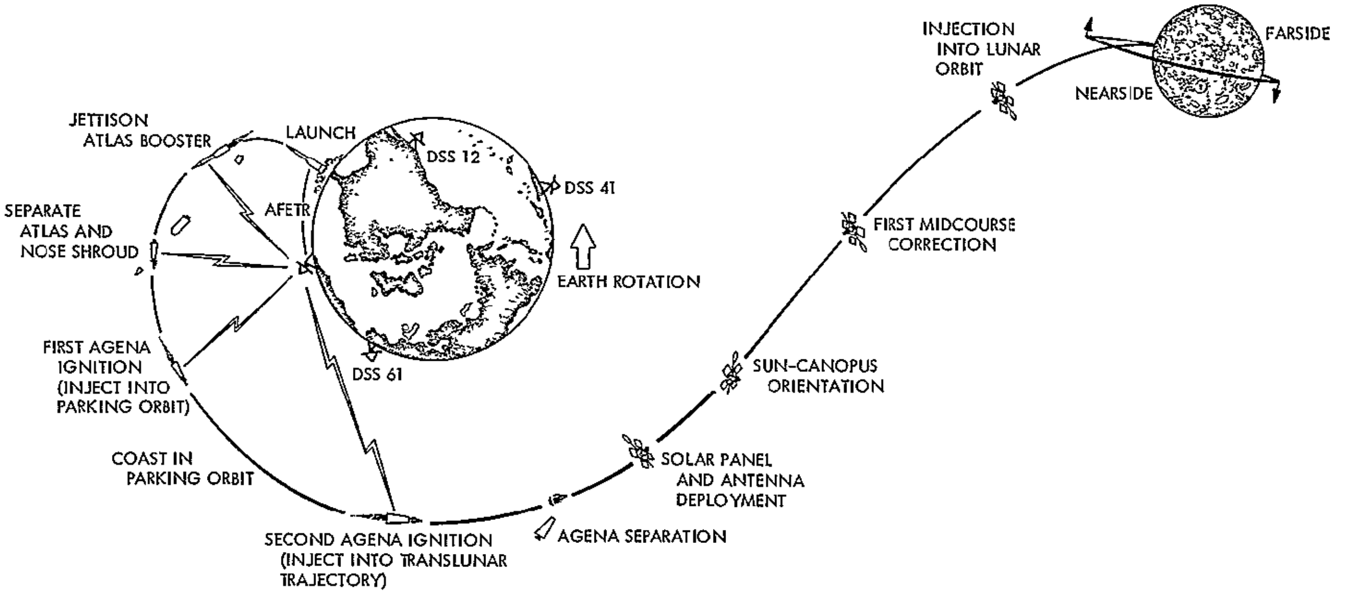

Fig. 3. Typical *Lunar Orbiter* flight profile

(5) The *Lunar Orbiter* software system was the most complex software operating and analysis system used to date by the DSN in support of spacecraft missions.

(6) The large amount of metric data gathered during five *Lunar Orbiter* missions led to the determination of an accurate lunar gravitational mass concentration model (MASCONS) during later JPL analysis of this data.

(7) First operational use of standardized DSN-supplied video tape recorders for primary data acquisition.

(8) First operational use of an automatic computer-driven pointing system for the 85-ft antennas (required during photo read-out).

(9) First use of a lunar orbiting spacecraft for retransmission of voice communications from earth.

(10) First use of an orbiting spacecraft for conducting bistatic radar mapping investigations of the lunar surface.

(11) First project use of DSS 71, the DSN Spacecraft Test and Monitor Facility at AFETR, for spacecraft prelaunch checkout. The DSS 71 RF link to the spacecraft was the only method used by the Project for communication with the spacecraft during the prelaunch phases.

3. *Management problems and experience.* The following is a list of some of the more significant management problems encountered and the experience gained during the *Lunar Orbiter* Project:

(1) Projects external to JPL can be supported effectively by the JPL TDS using a standardized interface support technique. There is, however, a necessity to provide projects external to JPL with more in-depth documentation of DSN equipment performance and interfaces. There was a lack of definitive documentation describing the DSN interface with the LOP during the early planning phases. This often resulted in misunderstandings of interface characteristics and caused additional work and expense for the Project. Typical examples of marginally defined interfaces were the ranging system design requirements and the SFOF software interface description.

(2) The JPL line function commitments to flight projects external to JPL are more difficult to discipline than are commitments to JPL-managed projects. The development effort in support of the TDS for a JPL-managed flight project is subject to both the JPL line function and TDS review and management, thus doubling the assurance that commitments to JPL-managed projects will be met.

(3) The single point of contact provided by the TDS to projects external to JPL resulted in more effective control and allocation of TDS resources to the flight project; this lead to more effective TDS management that was more difficult for a project to bypass.

(4) The SIRD–NSP documentation plan proved an effective device for matching project requirements and TDS capabilities for facility-type support; e.g., space requirements within facilities, DSS support, design parameters, etc. However, it did not prove effective for matching project requirements which were a function of time; e.g., allocating DSN resources in a multiple mission support environment.

(5) Because of cost limitations, only three DSS were equipped with *Lunar Orbiter* mission-dependent equipment. This seriously limited the capability of the DSN to schedule *Lunar Orbiter* passes in a multiple-mission support environment.

(6) The DSN was unable to meet a commitment to provide DSN personnel to man the *Lunar Orbiter* mission-dependent equipment at the overseas stations. As a result, Project personnel were required to remain on duty at both overseas stations until the end of the last photo mission. This staffing problem, together with (5) above, is further substantiating evidence that for efficient and effective support, mission operations at the DSS should not require the use of mission-dependent equipment or project personnel, particularly at the overseas stations.

(7) Effective scheduling of TDS resources in the multiple-mission support environment during the *Lunar Orbiter* Project support period was possible only through detailed negotiation with all projects and an hour-by-hour scheduling of facilities. NASA Office of Space Science and Applications (OSSA) support guidelines were of some assistance but were not effective without the direct involvement of responsible Project personnel working directly with the TDS.

II. *Lunar Orbiter* Project Requirements on the Tracking and Data System

A. Near-Earth Phase (Project Launch Phase) Requirements

The TDS defined the near-earth phase as extending from launch to first DSN two-way acquisition during the first DSN continuous view opportunity. For some purposes, including acquisition predicts responsibility, the near-earth phase extended from launch to launch plus 6 h.

A summary of Project requirements is provided in this section. Complete information on Project requirements placed on the TDS may be found in the LOP Support Instrumentation Requirements Document (SIRD) (see Bibliography.)

Coverage priority classes for all TDS near-earth resources were defined as follows:

(1) Class I: Requirements which reflect the minimum essential needs to ensure accomplishment of primary test objectives. These are mandatory requirements which, if not met, may result in a decision not to launch.

(2) Class II: Requirements which reflect the needs to accomplish all stated test objectives.

(3) Class III: Requirements which reflect the ultimate in desired support. Such support should provide the capability to achieve the test objectives earlier in the test program.

As a guide to a launch decision, the Project employed a matrix showing the operational readiness of the available resources which were capable of meeting Class II and Class III requirements.

1. Metric data. Metric data coverage during the near-earth phase was required by both the launch vehicle and spacecraft systems groups. The launch vehicle system group required metric data for first and second stage performance evaluations. The spacecraft system group required the same information to permit rapid alternate mission decisions in the event of nonstandard launch vehicle performance. This same metric data was also used to generate acquisition predicts for AFETR and MSFN down-range stations, and for the DSN stations responsible for early acquisition and support. Metric coverage of the spacecraft injection into the lunar transfer trajectory, and the subsequent separation from the *Agena* stage, was defined by the Project as being the most critical metric requirement. Range instrumentation ships (RIS) were also required on station in the launch corridor to fill gaps in land-based metric coverage for certain launch azimuths and injection locations. A typical *Lunar Orbiter* earth track from launch through injection into the cislunar trajectory is shown in Fig. 4.

Table 1 lists the launch vehicle metric coverage requirements in terms of Class I, II, and III priorities.

2. Telemetry. The launch vehicle system group required VHF telemetry coverage. Near-real-time transmission of critical launch vehicle performance data received at downrange telemetry stations was necessary for display at the AFETR launch vehicle analysis area. Spacecraft telemetry at S-band frequency was required during all critical events, and, most important, for those events after lunar transfer trajectory injection; e.g., spacecraft separation, and subsequent spacecraft solar orientation. Telemetry ships and aircraft, in addition to ground stations, were also required to fill in coverage gaps for some launch azimuth and injection locations. Ground commands to the spacecraft were not required during the near-earth phase. The Project requirements for near-earth phase launch vehicle and spacecraft telemetry are listed in Tables 2 and 3. Figure 5 shows the relationship of near-earth and deep space facilities to a typical earth track during launch and injection into the cislunar trajectory.

Table 1. Launch vehicle tracking coverage requirements

Required coverage interval		
Class I	Class II	Class III
Launch to *Agena* first cutoff plus 10 s	Launch to *Agena* first cutoff plus 10 s	Same as Class II
Any continuous 60 s between *Agena* first cutoff and *Agena* second ignition	Any continuous 200 s between *Agena* first cutoff and *Agena* second ignition	
Any continuous 60 s between *Agena* second cutoff and *Agena* retrofire start	From 60 s prior to *Agena* second ignition to retrofire plus 200 s	
Any 60 s after completion of *Agena* retrofire	Retrofire plus 200 s to battery depletion	

3. Ground communications. The Project requirements for TDS ground communications were directly related to Mission Control and real-time data analysis requirements. At launch, the Project required that voice communications from Mission Control, located at AFETR, be available to the SFOF and to critical data acquisition facilities of the MSFN and the AFETR. Support for real-time analysis required real-time data transmission from prime metric and telemetry stations to the AFETR Central Operations Control Area and Real-Time Computer System (RTCS). The AFETR was also required to transmit raw metric data from both AFETR and MSFN stations to the DSN in near-real time.

4. Data processing and display. The Project required the use of the AFETR RTCS for the rapid determination of parking orbit and post-injection orbit parameters. These orbit parameters were based either on actual launch time nominal trajectories or C-band radar metric data. The RTCS was used to generate acquisition prediction data for down-range AFETR and MSFN stations. The DSN was required to provide backup orbit determination during the near-earth phase, using raw AFETR and MSFN radar data. Displays depicting near-earth facility status were required by the Project in the Mission Control Area during the launch phase to assist in the launch decision process. The Project required that some specific telemetry parameters on both the S-band and VHF telemetry links be displayed in the AFETR-located Mission Control Center during the launch phase. These telemetry data were also required to be available at the SFOF for detailed analysis purposes.

5. Operations. The Project required that the Mission Director, and hence the Mission Operations Control

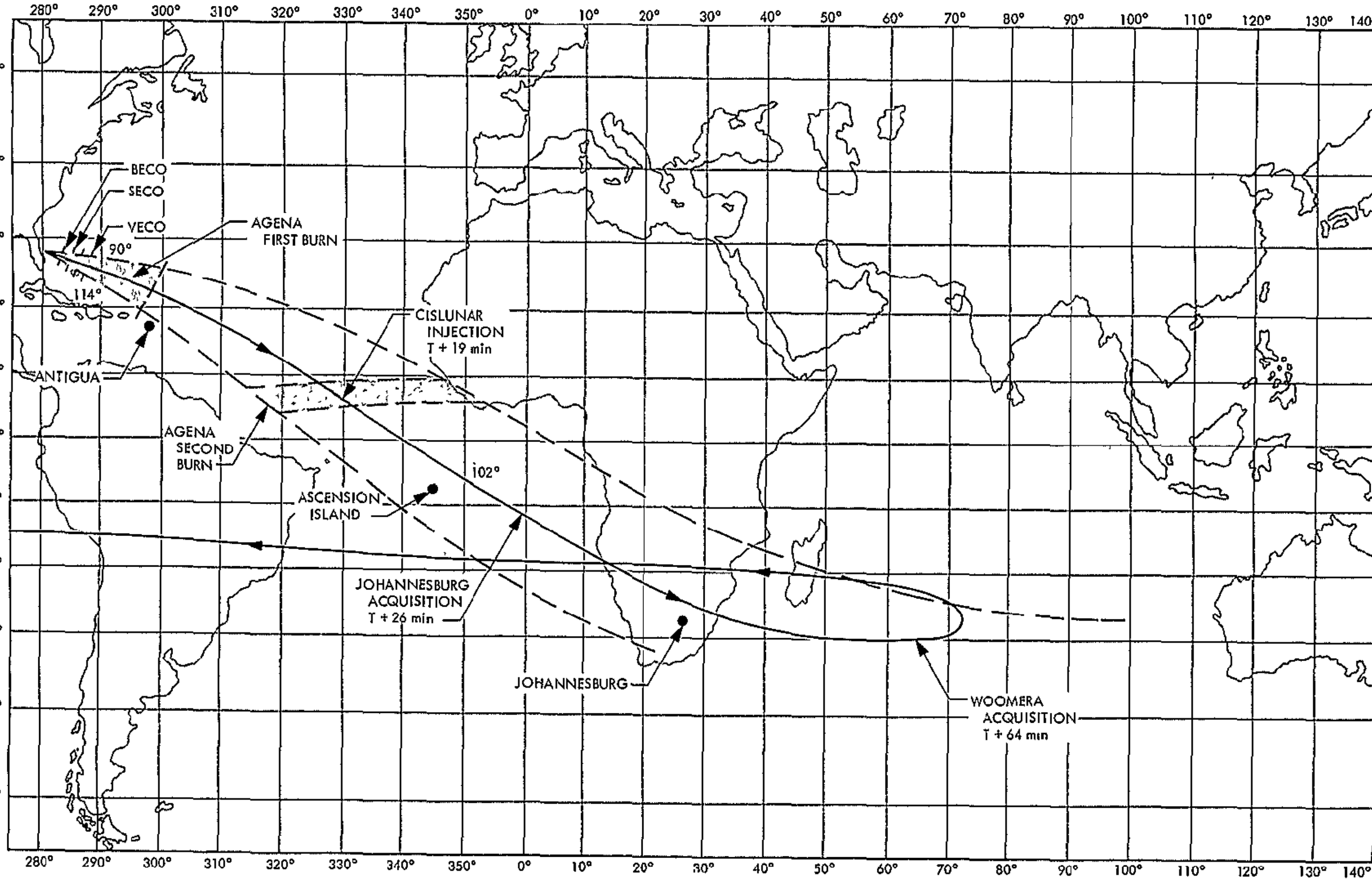

Fig. 4. Typical earth track

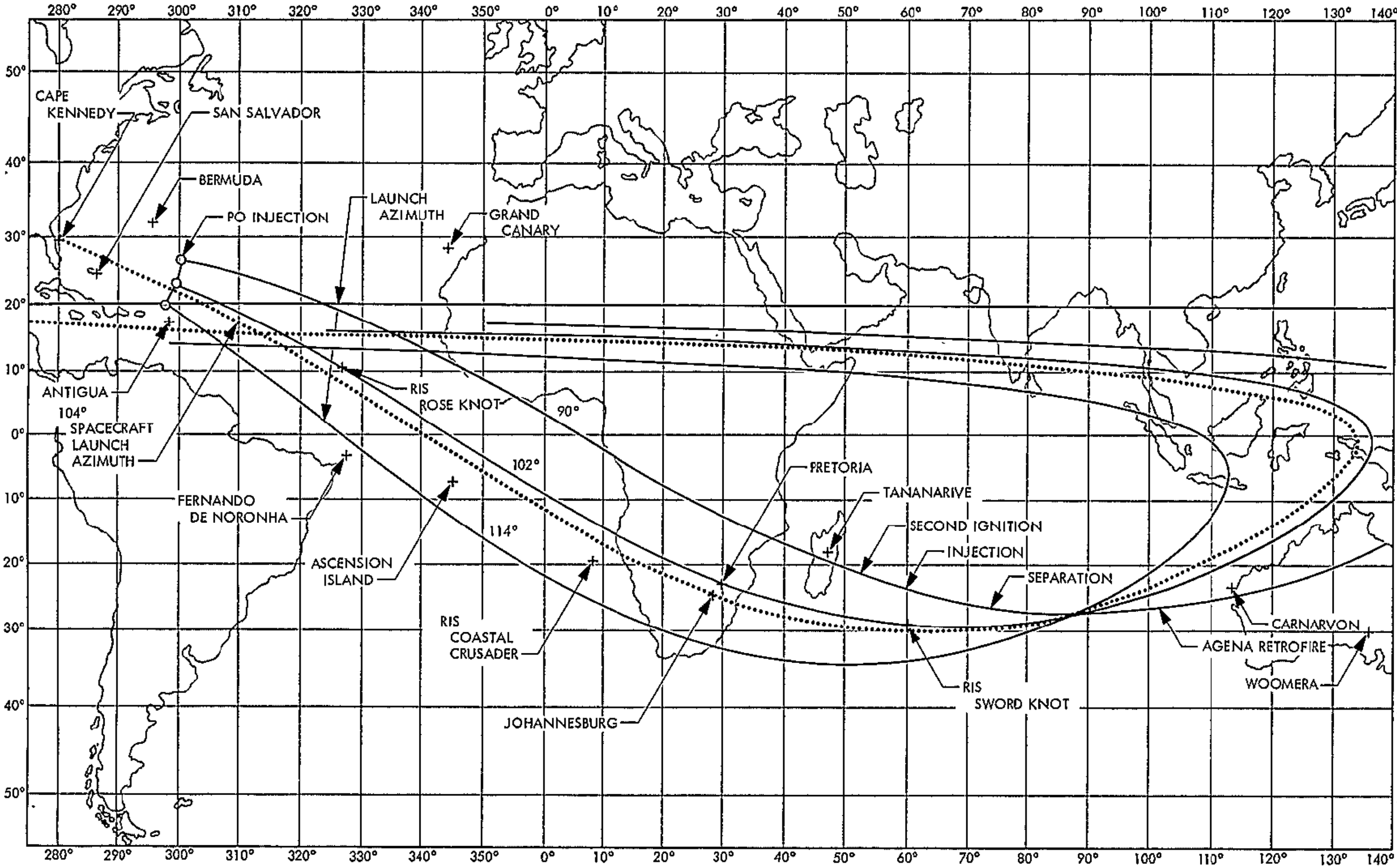

Fig. 5. Relationship of near-earth stations and DSS to typical earth track

Table 2. Launch vehicle telemetry coverage requirements

Agency	Class I	Class II	Class III
	Coverage interval		
Launch Vehicle Manager	Prelaunch calibrations From L-2 min to *Agena* first cutoff plus 25 s From *Agena* second ignition minus 20 s to *Agena* second cutoff plus 20 s From *Agena*/spacecraft separation minus 10 s to *Agena*/spacecraft separation plus 10 s From *Agena* retro-ignition minus 10 s to *Agena* retrofire cutoff plus 10 s	From acquisition of signal (AOS) to loss of signal (LOS) of the stations supporting the Class I requirements	Same as Class II

Center, be located at AFETR during the near-earth phase. The Project also required that DSS 71 in addition to spacecraft–DSN compatibility testing, also be available for spacecraft checkout use prior to launch. This was the first time that DSS 71 was used by a project in this manner. Monitoring and analysis areas for the Project, for the prime contractor, and TDS personnel were required at the JPL–AFETR Operations Center.

Table 3. *Lunar Orbiter* Project Class I spacecraft telemetry coverage requirements

Data source	Coverage interval	Delivery requirements
Agena link, Channel F (Channel F was a special VHF *Agena* telemetry subcarrier containing critical spacecraft data)	Prelaunch calibrations From launch to *Agena* first cutoff plus 20 s From *Agena* second ignition minus 20 s to *Agena* second cutoff plus 20 s From *Agena*-spacecraft separation minus 10 s to *Agena*-spacecraft separation	Data transmitted to DSS 71 in real time
Spacecraft link	Prelaunch calibrations From launch to *Agena* first cutoff plus 20 s From *Agena* second ignition minus 20 s to *Agena* second cutoff plus 20 s From *Agena* spacecraft separation minus 10 s to separation plus 18 min, or DSS 41 rise plus 5 min, whichever occurs first During periods of DSN visibility following initial acquisition	Data transmitted to DSS 71 in near-real time

Table 4. Deep-space coverage requirements

Interval	Required coverage
Launch to initial lunar injection	31 h/day, average over 4 days
Injection to completion of photo mission	24 to 31 h/day, as required by the Project
Completion of photo mission plus 30 days (selenodetic phase)	Three consecutive orbits, or 11 h, whichever is less, with one orbit or 3.5 h overlapping, whichever is less, every other day
From end of selenodetic phase plus 10 mo	Two consecutive orbits or 7 h, whichever is less, every third day with one orbit or 3.5 h, whichever is less, overlapping coverage each track period

B. Deep-Space Phase (Project Photographic Phase) Requirements

The photographic phase was defined by the Project as extending from initial DSN acquisition (two-way lock) to the end of the last photo readout. This phase was approximately 35 days long for each of the five *Lunar Orbiter* missions.

1. Metric data requirements. Lunar Orbiter metric data requirements are listed in Table 4. A three-station, 85-ft antenna network was required to provide continuous tracking coverage during the photographic phase. Overlapping station coverage was also required to permit more accurate orbit determination. Two-way doppler data were required almost continuously during the photographic phase. Ranging data were required to supplement two-way doppler data and to assist in rapid redetermination of the lunar orbit after spacecraft maneuvers. The angle data observable from the DSIF tracking stations is, generally, not useful for orbit determination purposes. An automatic computer-operated antenna pointing capability for the 85-ft tracking stations was required during photographic readout periods because the video transmission technique did not provide the coherent RF carrier necessary for automatic angle tracking.

2. *Telemetry and command requirements.* After initial two-way acquisition of the spacecraft by the designated DSIF station, continuous telemetry data acquisition and command transmission capability was required at each prime DSS during its tracking coverage period. Reception and recording of wideband spacecraft video transmissions was required during the photo readout mode. A video tape recording capability was required at each prime DSS for this purpose. *Lunar Orbiter* mission dependent equipment (MDE) for telemetry, video, and command data processing was supplied by the Project for installation at each prime DSS. *Lunar Orbiter* project personnel required to operate the equipment were to be in residence at each of the three prime DSN stations. Station TDS personnel were to be trained to assume most of the MDE operations after the first two missions. The station Senior *Lunar Orbiter* Engineer (SLOE) was to remain at the station as a backup Space Flight Operations Director (SFOD) until the end of the TDS support of the *Lunar Orbiter* Project.

Installation of Project-supplied photographic ground reconstruction equipment (GRE) was also required at each prime DSS, including a photographic darkroom facility.

The *Lunar Orbiter* was the first project requiring use of the on-site DSIF standards calibration capability for the calibration of MDE and supporting test equipment. On-site data processing computers were required to interface with *Lunar Orbiter* MDE and the Ground Communications Facility (GCF) equipment. These computers were part of the standard DSN Telemetry and Command Processor (TCP) Subsystem at each site.

3. *Ground communications.* The Project required the use of a high-speed data line for transmission of telemetry information from the DSS to the SFOF. During the later missions, the GCF high-speed data line was required to transmit simulation data from the SFOF to the DSN stations. Teletype was required for use as a telemetry backup from the stations. Near-real-time transmission of command data from the SFOF to the DSS was required. The Project required real-time transmission of video data to the SFOF from the DSS at Goldstone. A 6-MHz microwave link was necessary to support this function. The overseas DSS video data interface with the Project was located at the receiver for MDE processing or at the video tape recorder output. The TDS was not required to handle or mail video tape recordings and film data from the overseas stations. This responsibility was retained by the Project and performed by the resident Project personnel at these stations. Teletype lines and voice lines from the SFOF to LRC and to The Boeing Company in Seattle, Washington, was required to allow Project specialists at these locations to assist in the analysis of data.

4. *Data processing and display.* Data processors for analysis of telemetry, command, and metric data at the SFOF were required by the Project. During critical periods of each mission, two separate data processors were needed to meet processing requirements, although the DSN had suggested that all Project programs be integrated in only one SFOF computer string so that the second string could be available as a backup. Table 5 lists the required central processor support for the photographic mission.

The software resident in the data processors consisted of the Project data analysis programs and the DSN software operating system and was the joint responsibility of the *Lunar Orbiter* Project and the TDS. The development of both Project and TDS software proceeded simultaneously. During this time, however, a misunderstanding of the interface between the two systems produced a "grey area" of responsibility containing a significant portion of the software effort which was left undone. This grey area was in part caused by the concurrent development effort but was more directly the result of insufficient formal documentation defining the interface which was located in the center of a computer. By mounting an intense software development effort, supported by both The Boeing Company and the DSN, the Project was able to produce the requisite software in time for the first launch. The TDS was required to integrate all programs and to provide a tape library of project-independent computer operating programs.

Table 5. Required DSN computer support and configuration in the SFOF

Support interval		Configuration		
Start	End	Category I	Category II	Category III
L−12 days	L−9 days			X
L−9 days	L−2 days	X		
L−12 h	L+10 h	X		
L+10 h	First midcourse minus 20 h		X	
First midcourse minus 20 h	First midcourse plus 4 h	X		
First midcourse plus 4 h	Second midcourse minus 20 h		X	
Second midcourse minus 20 h	Second midcourse plus 4 h	X		
Second midcourse plus 4 h	Injection into lunar orbit minus 20 h		X	
Injection into lunar orbit minus 20 h	Second transfer plus 7 h	X		
Second transfer plus 7 h	End of photo taking			X
End of photo taking	End of photo read-out		X	

Category I: One prime computer string and one alternate string both configured to Mode II. These strings may be run simultaneously. This category was to be used only during critical periods.

Category II: One prime computer string in Mode II with access to another Mode II string as an alternate, within a 30-min period.

Category III: Category II with the addition of a computer operating in Mode IV. Mode IV computers in Category III were to be committed at a maximum of 112 h/wk. Mode II configuration for the additional computer was to be "best-efforts" only. Committed coverage: photo mission (period from launch to L+35 days).

Computer Mode II: IBM 7044—1301 shared disk file—7094.

Computer Mode III: IBM 7044 only; real-time input/output (I/O), display, log tape.

Computer Mode IV: IBM 7094 only; postprocessing mode, using 7044 log tape and/or direct card inputs.

5. *Mission control interface and analysis areas.* The Project and the TDS agreed that the Deep Space Mission Control interface would be at the SFOF. To implement this, the Project required mission operations areas and mission analysis areas to be located in the SFOF. The Mission Director was located at JPL during the entire mission except for the near-earth phase.

To provide a backup mission control capability, the Project required that each DSS be capable of minimal spacecraft housekeeping support in the event of a communications failure with the SFOF. Project personnel in residence at the DSS were trained to perform this backup mission control function.

Table 6 lists those mission control and analysis areas in the SFOF required by the Project. Computer I/O consoles, printers, and plotters were also required in these areas for the conduct of mission operations. A photographic processing area was also required by the Project for real-time assessment of the operation of the photo system during Goldstone DSS view periods. This requirement was met by making available to the Project the *Surveyor* film processing facility in the SFOF (Fig. 6). *Lunar Orbiter* film was exposed, developed, and assembled in mosaics for this photographic quality assessment.

Table 6. Mission control and analysis area allocations in the SFOF

Area	Area, ft^2	Usage interval
SPAC	1800	Continuous
FPAC	1200	Continuous during photo mission
GRE	400	
Mission Control	150	
Mission operations	200	
Advisors area	1000	Shared
Photo processing area	Shared with *Surveyor* Project	

6. *Master data record.* The *Lunar Orbiter* Project provided their own master data record capability for the tracking, telemetry, and command systems; the DSN was not required to maintain a master data record library.

C. Deep-Space Phase II (Project Extended Mission Phase) Requirements

The extended mission phase support requirements on the TDS were shared with that coverage provided for the most recently launched spacecraft. During the extended mission phase, providing there were no spacecraft operating in a photo mission phase, the Project expected a total of approximately 14 passes/wk for all operating spacecraft. Analysis areas and associated computer processing capabilities were to be maintained, but on a low-priority basis. A significant extended mission phase requirement added later in the program was to assist

Fig. 6. Typical *Lunar Orbiter* photographic mosaic is assembled in the GRE area in the SFOF. The process was used for near-real-time quality assessment of *Lunar Orbiter* photography

the MSFN in its tracking qualification for cislunar and lunar orbiting spacecraft.

The TDS resources used for the support of the extended mission phase for all spacecraft were approximately 25% of the resources used during the photographic mission phase for one spacecraft.

A large number of special engineering, operational, and scientific experiments were conducted during the extended mission phase. Although designated as low-priority requirements, the following tests of note were conducted:

(1) A multiple spacecraft lunar orbiting operations experiment. Considerations included RF and command address interference and multiple mission analysis operations.

(2) A voice relay experiment transmitting from one DSS to the *Lunar Orbiter* spacecraft and back to a second DSS.

(3) A convolutional coding and sequential decoding experiment using the turnaround ranging channel of a *Lunar Orbiter* spacecraft.

(4) Ranging and doppler experiments using a bistatic radar configuration for lunar surface mapping investigations.

(5) Use of a *Lunar Orbiter* spacecraft as a model to measure transponder ranging time delay stability, in an attempt to determine charged particle effects.

(6) Use of *Lunar Orbiter* metric data for lunar gravitational field studies and DSN inherent accuracy studies.

III. TDA Requirements and Constraints on the *Lunar Orbiter* Project

A. General

The following are summary descriptions of the equipment and mission design areas wherein significant requirements and constraints were placed on the *Lunar Orbiter* Project by the TDS. Detailed requirements are listed in the NSP.

B. Near-Earth Phase

*1. **Trajectory design.*** The launch azimuth and injection latitude were constrained to fit Project coverage requirements. The Project was required to supply detailed trajectory information to the TDS at least 6 wk prior to launch, for coverage analysis and determination of the coverage capability of the near-earth facilities.

*2. **C-band transponder.*** A C-band radar transponder was required on the launch vehicle in order to obtain accurate AFETR and MSFN metric data.

*3. **Antenna patterns.*** Acceptable antenna design and antenna pattern data for the launch vehicle VHF and S-band telemetry systems and for the radar transponder were required from the Project so that the TDS could determine coverage constraints and provide the required coverage.

*4. **Compatible telecommunications system.*** The design of both VHF and S-band telemetry systems (modulation, subcarriers, etc.) was required to be compatible with the near-earth telemetry reception equipment. Specific tests were required to demonstrate the compatibility of all telecommunications equipment. DSS 71 was used by the TDS to assure prelaunch S-band compatibility with a given spacecraft. The AFETR provided a telemetry station for prelaunch VHF telemetry compatibility tests.

5. Real-time telemetry data capability. The Project was constrained to the use of a limited number of VHF telemetry data channels for transmission of real-time telemetry data to Mission Control at AFETR. This requirement forced launch time and azimuth constraints on the trajectory.

6. Aircraft and shipboard coverage. There were no special requirements placed on the Project concerning aircraft or shipboard coverage; however, the TDS could not commit to real-time data transmission from aircraft or shipboard telemetry and metric coverage facilities.

7. Real-time metric data capability. The DSN requirements for near-earth metric data are shown in Table 7.

C. Deep-Space Phase

1. Compatible S-band tracking and communications. The Project was required to provide a compatible telecommunications system design to interface with a standard DSS configuration. The central requirement was the incorporation of a DSN-compatible S-band transponder on board the spacecraft. Subsequently, JPL provided extensive consulting support during the development of this transponder.

Table 7. The DSN requirements for near-earth metric data

Required coverage interval		
Class I	**Class II**	**Class III**
From first Agena cutoff to plus 60 s Any continuous 60 s between Agena second cutoff and Agena retrostart	From first Agena cutoff to plus 180 s From Agena second cutoff to plus 2 h	From first Agena cutoff to Agena second ignition From Agena second cutoff to loss of track
Delivery requirements		
Data transmitted to JPL/AFETR within 30 min of occurrence	Data transmitted in real time	Same as Class II

A considerable amount of testing was required to demonstrate spacecraft tracking and communications compatibility with the DSIF. These compatibility tests involved ranging, doppler, telemetry, and command system performance and were required to be conducted at Goldstone.

2. Design of DSN initial acquisition. The Project was required to provide a detailed first acquisition parametric analysis for each spacecraft launching. These data were to assure that the planned trajectory and mission operations requirements were within the DSN design constraints for a satisfactory acquisition. Data transmission from the initial acquisition DSS was not committed prior to 30 min after initial acquisition.

3. Standard trajectory predicts. The Project was required to provide the DSN with standard trajectory acquisition predicts data for the entire launch period of a given monthly launch opportunity.

4. The DSS display of RF tracking parameters. The Project was required to provide a local DSS display of selected spacecraft transponder RF parameters from the spacecraft telemetry data stream.

5. Central processor loading constraints. The Project was constrained to the use of one SFOF computer string (IBM 7044/7094) for operation of the complete operational software system in the SFOF. The second computer string was to be made available only as a back-up during critical periods. The same constraint applied to the TCP Subsystem computers at the DSS.

6. Software interface. The Project user analysis programs were required to interface with a standard TDS-supplied operating system. This requirement was also imposed on simulation programs to be used in the Simulation Data Conversion Center (SDCC) computer system.

IV. TDS Planning and Implementation Effort

A. TDS Planning Organizations

1. The TDS manager. The TDS Manager is responsible for specifying, coordinating, implementing, and matching the various TDS resources to support the LOP. He is also responsible for obtaining the AFETR, MSFN, NASCOM, and DSN support commitments and for guaranteeing the integrity and readiness of the support at launch. The MSFN Operations Manager, the NASCOM Operations Manager, and the DSN Manager for the LOP were responsible to the TDS Manager for the facility or network support in their particular areas. The interface with AFETR was coordinated through the Kennedy Space Center (KSC) by the JPL organization at Cape Kennedy. A Near-Earth Phase Project Engineer was appointed by JPL–AFETR.

2. *Major TDS activities.* The following major TDS activities were accomplished during the interval from August 1964 to August 1965:

(1) Established a data flow configuration.

(2) Negotiated and established both agency and technical interfaces.

(3) Established interface specifications for hardware and software.

(4) Assisted and coordinated the development of a *Lunar Orbiter* mission operations technique.

(5) Specified detailed facility commitments.

(6) Designed and implemented the TDS hardware and software required for support of the LOP.

The following major activities were accomplished during the interval from August 1965 to April 1966:

(1) Integrated *Lunar Orbiter* hardware and software into the TDS facilities.

(2) Verified the TDS *Lunar Orbiter* hardware, software, and operations interface through the use of compatibility tests.

(3) Initiated changes in hardware, software, and procedures resulting from testing.

(4) Conducted prelaunch training tests.

(5) Conducted Operational Readiness Tests (ORT).

The following major activities were accomplished during the interval from April 1966 to March 1968:

(1) Mission support.

(2) Participated in Project Launch Readiness and Post-Launch Reviews.

(3) Initiated changes in support resulting from new Project requirements in hardware, software, and procedures.

(4) Initiated changes in support resulting from other spacecraft project requirements on the TDS; i.e., *Surveyor*, *Mariner V*, and *Pioneer*.

(5) Scheduled the TDS facilities support for *Lunar Orbiter* in a multi-project support environment.

3. *Near-earth planning organization.* The near-earth phase planning organization is shown in Fig. 7. The TDS Near-Earth Project Engineer was responsible for coordinating near-earth phase requirements, as committed in the NSP and Project Support Plan (PSP), with the MSFN *Lunar Orbiter* Manager, KSC (for AFETR), and the NASCOM *Lunar Orbiter* Manager. The operational and equipment/facility configuration planning and implementation were both managed in this manner. There was, however, no direct method for coordinating support changes within the AFETR because of the channeled AFETR management structure as shown in Fig. 7. Most of the direct planning support was accomplished within the NASA Project Division Staff by the various range functional planning elements shown at the bottom of Fig. 7.

4. *The deep-space planning organization.* The essential deep-space phase planning organization is shown in Fig. 8. The DSN Manager was responsible to the TDS Manager for the DSN configuration implementation and readiness. He was supported by the DSN Project Engineer (PE), who had the basic responsibility for the DSN system engineering function in support of *Lunar Orbiter*. The DSN PE was supported by a design team consisting of DSIF, Space Flight Operations Facility (SFOF), software, and GCF Project Engineers.

An overall telemetry and command data flow diagram (Fig. A-1) was developed during the early DSN–LOP planning stages, and was used as an effective mechanism to specify the interface and interface responsibilities for the DSN and the LOP. The diagram helped to identify critical paths and possible alternates, clarify requirements for interface specifications, organize the requirements for a compatibility test plan, provide the structure for an orderly change control mechanism, and provide a basis for justifying new requirements. Probably more than any other instrument, the data flow diagram provided the framework for the effective system design of the DSN–LOP interface.

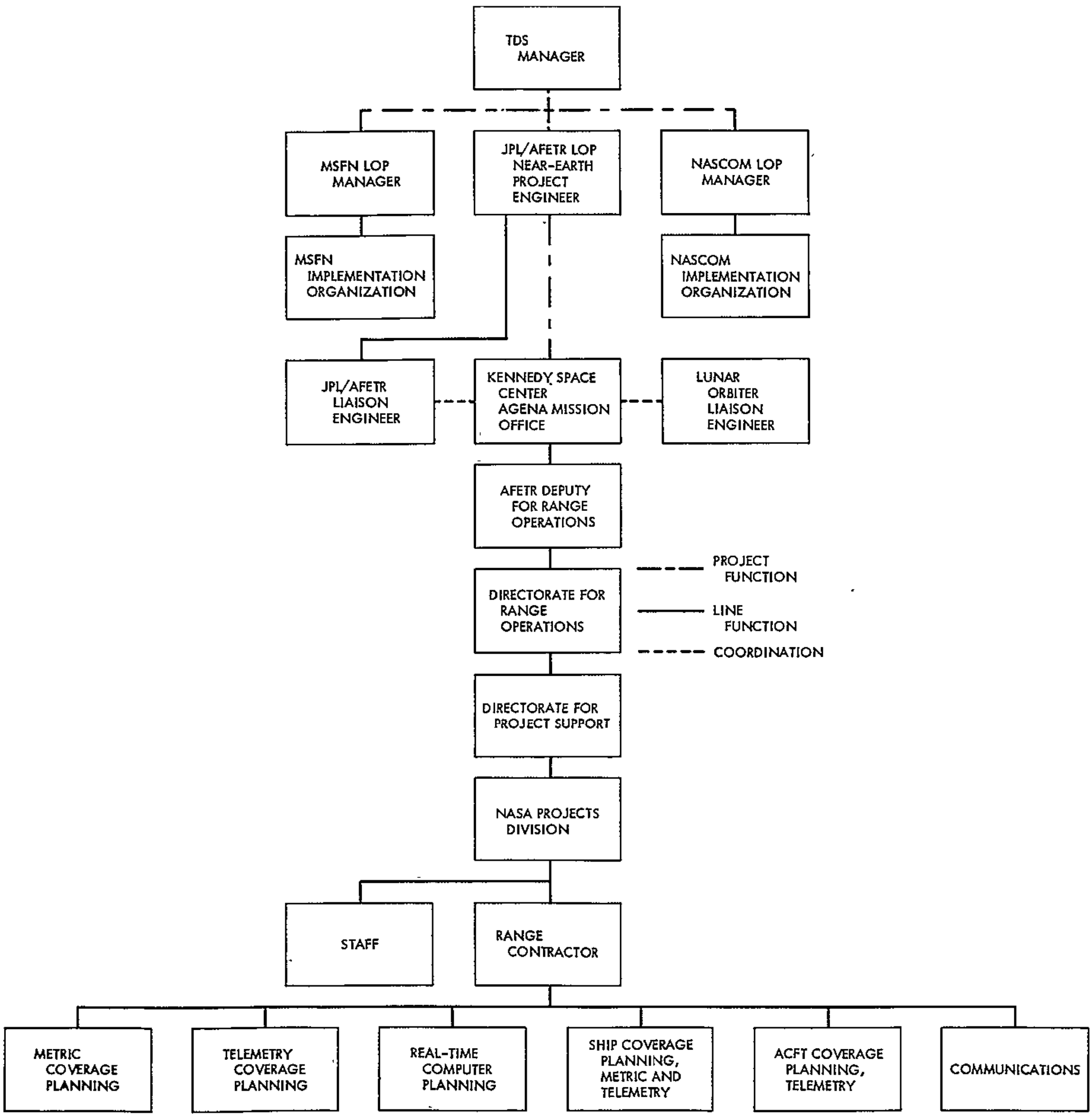

Fig. 7. Near-earth planning organization

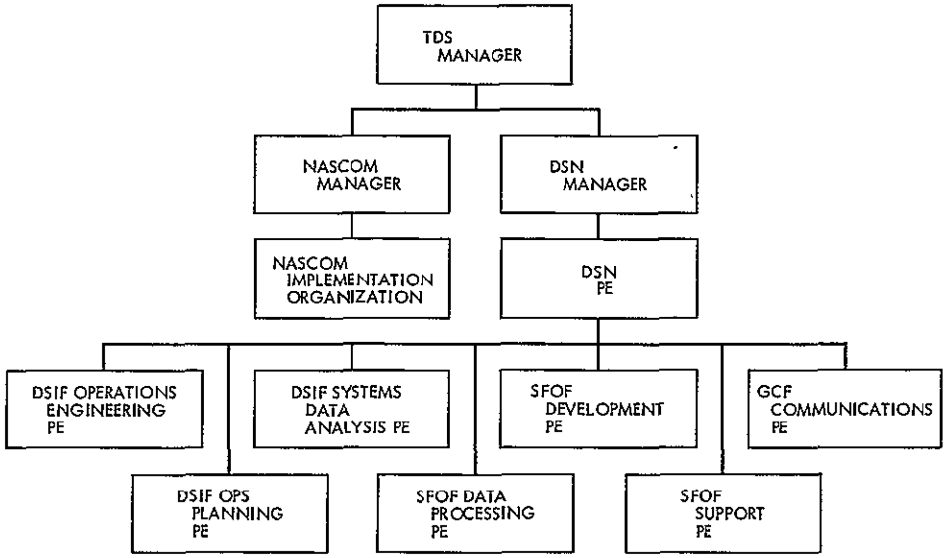

Fig. 8. Deep-space planning organization

5. The TDS–Lunar Orbiter operations planning organization. Early in the planning stage of the first mission, a Space Flight Operations Working Group was established with membership from the LOP (LRC and the Boeing Company) and JPL–TDS. Its purpose was to plan the detailed operations and time-line analysis necessary to support each mission. In accomplishing this, the group drew heavily on prior DSN experience with other spaceflight projects. This organization was also used as an effective tool to plan DSN–Project interfaces in the SFOF involving Flight Path Analysis and Command (FPAC) functions, Spacecraft Performance Analysis and Command (SPAC) functions, and SFOD–mission operations interfaces.

B. Configuration Management

Near-earth phase configuration management was provided by internal AFETR, MSFN, and NASCOM elements. The DSN configuration control in the hardware and software areas was disciplined with an internal DSN configuration control document. Hardware configuration control was specified down to the functional and interface level, and was committed to the Project on a per-launch basis. Modifications to the standard configuration were further disciplined with a formal change control technique. After final configuration verification testing prior to the launch, the DSN facilities imposed a configuration freeze which was maintained through the critical phase of each mission. The DSIF configuration freeze was imposed approximately seven days prior to launch and remained in force until the end of the photographic mission. The DSIF configuration could be effectively controlled because the DSIF stations did not usually operate in a multimission environment during the critical phases of the Project. The GCF configuration maintained critical support capability, but did not freeze any given hardware. The SFOF configuration was also frozen, but because of the multimission environment, the freeze was imposed only from a few days prior to launch up to lunar orbit insertion. The freeze was lifted at this time to accommodate the requirements of other projects.

The definition and management of the DSN configuration during 1964–1966 was not without difficulties. The design and implementation of the LOP interface took place during a period when both the DSIF and the SFOF were undergoing significant modification and upgrading, while at the same time, the DSN was establishing a configuration management system. To add to the management difficulty, a JPL engineering planning document (EPD), containing configuration estimates that did not materialize, was written into the LRC–Boeing Company contract as a design interface document. It was not realized that the document was only to be used for planning purposes and could not be used as a commitment document. Subsequently, it was decided that each interface required definition on an individual basis. The resulting interface descriptions and commitments were provided in another EPD, the DSN–LOP configuration control and interface document.

The *Lunar Orbiter* software system was probably the most complex yet trouble-free system ever supported by the DSN. The software system consisted of 28 LOP Programs and 13 DSN Programs. The DSN was committed to provide mission-independent program support, the executive routine, software integration, and to man the Real-Time Software Controller data control (DACON) position. A change control technique was developed by the responsible DSN and LOP software groups to establish a software configuration management system. The essential elements of this configuration management system are shown in Fig. A-2.

The *Lunar Orbiter* analysis software did not change greatly since the requirements for each mission were essentially the same. There were, however, some interface changes imposed by the DSN on the Project. It had been originally planned to reprogram the *Lunar Orbiter* software system to operate with the DSN "7044 Redesign" operating system which allows a number of software systems to use the same computer simultaneously. By the time the 7044 Redesign was operational, however, the integration of the *Lunar Orbiter* system into it would not have been cost-effective since only Mission V could have utilized the system, and this requirement was not implemented. A major software interface change during the *Lunar Orbiter* support period was imposed on the *Lunar Orbiter* Project by the TDS with the installation of the JPL Communications Processor for teletype switching. While this did not affect the real-time telemetry input to the IBM 7044, it did require major interface changes in the IBM 7044 metric data system interface. The second major software change made during the course of the Project was to shift simulation support from the System 1 PDP-1 Computer to the System 2 ASI-6050 Computers.

C. Scheduling Technique

The *Lunar Orbiter* spacecraft was scheduled to launch on three-month centers throughout the program. The first launch occurred in August, 1966, and the fifth and last was in August, 1967. With the exception of an initial three-month delay, each launch opportunity was met. Support was provided during a time when TDS facilities were heavily loaded. The AFETR, MSFN, NASCOM, and DSN facilities were faced with numerous conflicts created by simultaneous support requirements for *Lunar Orbiter*, *Surveyor*, *Pioneer*, and *Mariner* Projects. These were resolved through judicious scheduling, interproject compromise, and the use of priority ground rules established by the Office of Space Science and Applications (OSSA).

The overall TDS scheduling mechanism used for *Lunar Orbiter* is shown in Table 8. As noted in the first column, the DSN utilized a 7-day schedule and 7-day forecast, a 12-wk schedule, and a 16-mo schedule to satisfy short, medium, and long-term requirements, respectively. Only the 7-day schedule involved the inclusion of hour-by-hour scheduling requirements. The 12-wk schedule was limited to the determination of gross fits only, and time-sensitive conflicts within a 24-h period were not visible. In some cases, the DSN facilities generated separate, detailed, hour-by-hour monthly schedules in order to obtain the necessary visibility for providing coverage commitments 1 mo in advance. The DSN 16-mo schedule

Table 8. The TDS scheduling mechanism

Scheduling period	DSN	AFETR	NASCOM	MSFN
Short term	7-day and 7-day forecast. Hour-by-hour scheduling weekly	1-wk. Updated in real time. Hour-by-hour scheduling weekly	7-day schedule	7-day and 7-day forecast. Daily update
Medium term	12 wk. Total loading only of each resource. No time-phased resolution. Start one month ahead	6-mo forecast. Updated once per week. Total loading		
Long term	16 mo. Total loading of gross facilities, antennas, computers, etc.	PRD only	12-mo forecast	6-mo forecast
Remarks	Individual facilities had separate schedules for long-term, hour-by-hour scheduling			

permitted long-term planning of facilities and indicated changes in DSN coverage requirements. Such requirements as relocation of *Lunar Orbiter* MDE from DSS 61 to DSS 62 and the need for additional SFOF computers were detected in time to provide the necessary project coverage.

The DSN PE was responsible for providing LOP schedule requirements to the DSN. The JPL–AFETR PE, in conjunction with the Project, provided schedule inputs to the AFETR, NASCOM, and MSFN for the near-earth phase.

D. TDS Supporting Documentation Flow

The TDS documentation requirements for the planning, implementation, and operations necessary to support the *Lunar Orbiter* Project are shown in Fig. 9. The

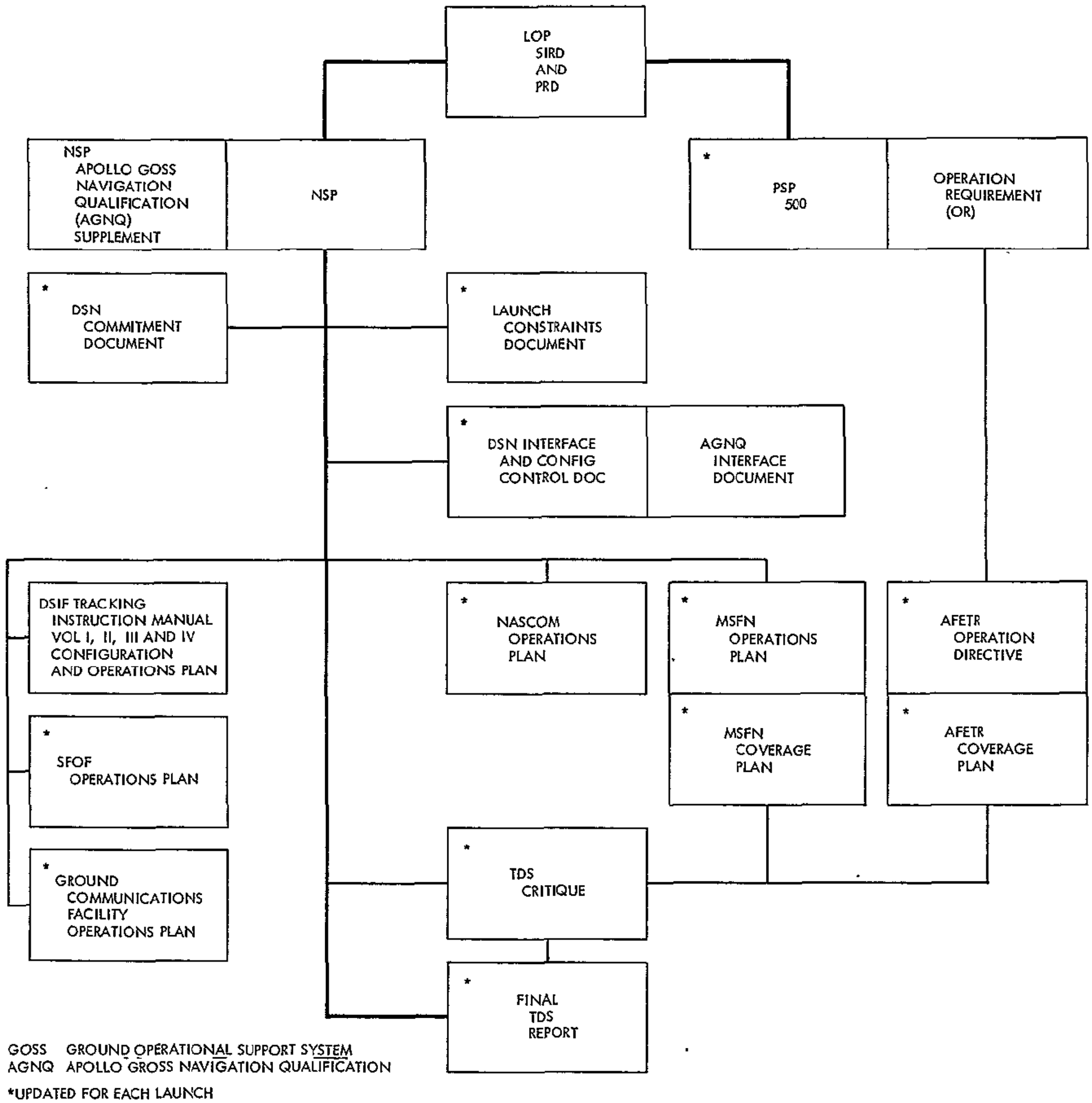

Fig. 9. TDS–LOP interface documentation

capability documents which were necessary for preliminary mission definition and planning are not listed.

The basic documents placing requirements on the TDS were the SIRD, and its derivative, the AFETR Program Requirements Document. The TDS response to these documents in terms of capability and actual resources available for support, was contained in the NSP for the DSN, MSFN, and NASCOM support commitments, and in the instrumentation portions of the Program Support Plan (PSP) for AFETR support commitments. These two documents comprised the TDS commitment for Project support. Minor changes to these commitments necessitated periodic updating of these documents for support of *Lunar Orbiter* launches. Because of the long document review cycle, it became necessary to publish supplements to the PSP, a separate DSN commitment document, and separate TDS launch constraints documents for each launch in order to provide the Project with timely changes defining the available TDS support. A modification of the NSP concept is recommended for Projects such as *Lunar Orbiter*, which involve successive launches over long time periods.

E. TDS Reviews

Prelaunch TDS reviews of tracking and telemetry coverage, facility commitments, and corrections to previous coverage inadequacies were held approximately three weeks prior to each launch. The TDS Manager, supported by various TDS facilities, presented the TDS readiness status at the Launch Readiness Review, usually held two weeks prior to each launch. Action items which developed at these reviews were assigned for compliance prior to launch.

Near-earth postlaunch reviews were held 2–4 wk after launch. The DSN postphotographic phase reviews were held 6 wk after launch, or approximately 2 wk after the completion of the photo mission. Action items generated during these reviews were usually scheduled for compliance prior to the next launch.

The responsible TDS Managers for the active NASA projects using the AFETR–NASCOM–MSFN–DSN for TDS support, organized a tracking panel to: (1) coordinate the implementation schedules of new capabilities, such as metric and telemetry ships, new metric radars, and new land-based telemetry capabilities, (2) establish a coordination discipline over the various TDS elements to correct TDS deficiencies, (3) provide an arena to discuss common TDS Project interface problems among the various projects, (4) provide the NASA Office of Tracking and Data Acquisition (OTDA) with the TDS status for each project, and (5) to coordinate the interfaces between TDS facilities in order to achieve the requisite coverage in an efficient and reliable manner.

V. Tracking and Data System Configuration for *Lunar Orbiter*

A. Near-Earth Phase Configuration

1. Operations organization. A simplified diagram of the TDS AFETR Operations Organization showing only the major TDS support elements is shown in Fig. 10. Building AO contains the JPL–AFETR Field Station which consists of the JPL–AFETR Operations Center and Communications Center. The Near-Earth PE functioned as the key coordinator for the Near-Earth Operations Organization and was responsible to the TDS Manager for the real-time operational interface and liaison with the major support elements. The operational interface under the control of the Near-Earth PE involved the following activities:

(1) Monitoring the launch phase and keeping TDS and Project personnel in the MSFN Mission Operations Center (MOC) and SFOF informed of the status of MSFN and AFETR stations, ships, and equipment, launch vehicle and spacecraft status, progress through the countdown, and the occurrence and time of inflight events.

(2) Receiving, and keeping Project personnel at Cape Kennedy informed of reports on the status of DSN systems, stations and equipment, and their readiness to support the mission.

(3) Providing liaison between the FPAC group and the AFETR RTCS, through the JPL Data Coordinator stationed at the RTCS.

(4) Receiving MSFN and AFETR metric tracking data and computed data, including DSN acquisition information, and retransmitting these data to the SFOF.

(5) Receiving and retransmitting RTCS orbital information to Bldg. AE.

(6) Receiving DSN tracking data from the SFOF and retransmitting that data to the RTCS for use in RTCS orbital computations.

(7) Coordinating launch phase TDS activities, performing analyses of current readiness during the

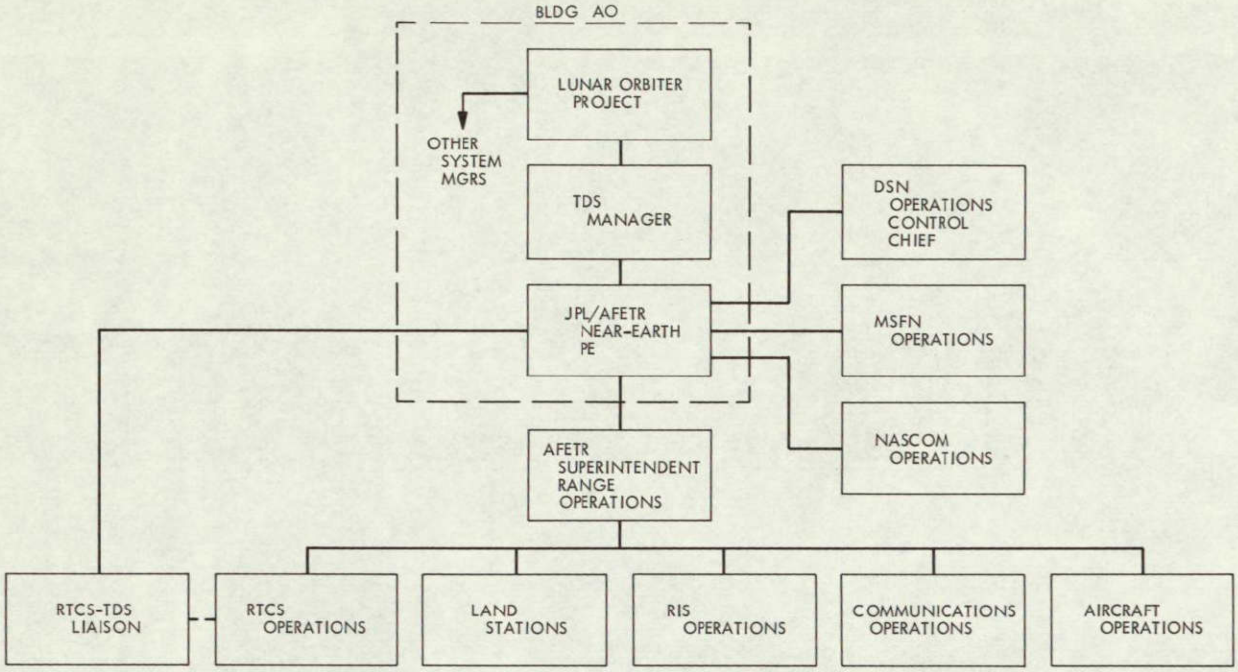

Fig. 10. Simplified TDS near-earth operations organization

countdown, and evaluating TDS performance during the near-earth phase.

2. Tracking metric data flow, data processing, and display. The near-earth metric data flow from AFETR, MSFN, and DSN metric data sources is shown in Fig. 11. The DSN computers at the SFOF and the AFETR RTCS at Cape Kennedy processed much of the same data, and were used to provide cross-support for each other.

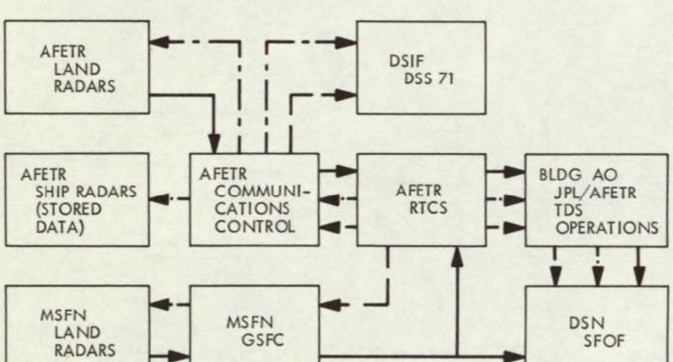

Fig. 11. Simplified near-earth metric data flow diagram

a. *Data processing.* The RTCS at Cape Kennedy processed metric data received from the AFETR and MSFN sites. The RTCS basic data processor consisted of CDC 3600 and 3100 Computers. Launch vehicle and spacecraft acquisition prediction information was computed and transmitted to the various TDS sites supporting the near-earth phase. Acquisition prediction information was transmitted in the form of interrange vectors (IRV) and standard tracking parameter listings.

The RTCS was also used to compute orbits from near-earth tracking data as a check on trajectory performance. A number of orbits were computed based on (1) actual parking orbit conditions, (2) nominal and actual transfer orbit conditions, and (3) actual postposigrade conditions. Postposigrade lunar mapping orbits were generated from both radar and DSN tracking data inputs.

b. *Data flow.* Teletype metric data from all MSFN radar units were retransmitted to GSFC to allow the MSFN to generate acquisition predicts for its own stations. Near-earth radars tracked only the *Agena* stage and were not capable of tracking the separated spacecraft for any significant distance. The AFETR radar tracking data were transmitted to the JPL–AFETR Operations Center at Bldg. AO (Fig. 12). High-density tracking data received from the Bermuda and Carnarvon radar units were converted to decimal format and

Fig. 12. Near-earth operations surveillance and information center located in Bldg. AO at Cape Kennedy

sent to Bldg. AO. Appropriate metric data were then selected as needed by the JPL/AFETR personnel at Bldg. AO. Appropriate metric data were then selected as needed by the JPL–AFETR personnel at Bldg. AO and transmitted via teletype to the SFOF at Pasadena, Calif. Subsets of selected DSN metric data were also sent to the RTCS and used as necessary to verify the nominal DSN station predicts, or to produce updated predicts for the DSN stations based on current data.

*3. **Telemetry data flow.*** The near-earth down-range telemetry data flow configuration for S-band and VHF telemetry is shown in Fig. 13.

*4. **Near-earth support summary.*** Table 9 lists the near-earth facilities that provided *Lunar Orbiter* support. Table 10 lists the NASCOM circuits utilized to support both the near-earth and deep-space phases of TDS support for *Lunar Orbiter*.

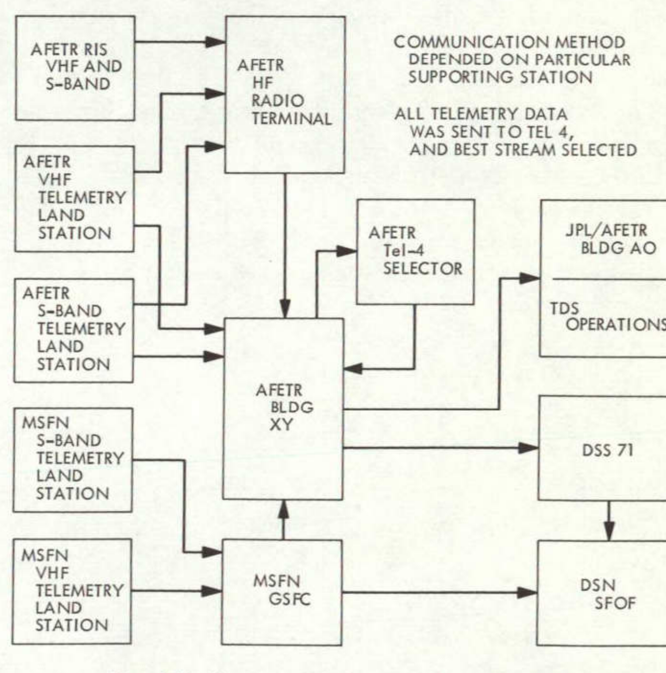

Fig. 13. Near-earth basic telemetry data flow diagram

B. Deep-Space Network Configuration

*1. **Operations organization.*** A simplified operations diagram showing the method used to provide DSN operational support for the LOP is depicted in Fig. 14. Also shown, for purposes of clarifying the LOP–DSN interface, are the *Lunar Orbiter* Project operations elements. The DSN PE was responsible for the compatibility of the DSN systems and operations supporting the LOP. For the first two missions, the DSN PE, or his designate, monitored the interface between the Project Flight Operations Control and the DSN Operations Control Chief

Table 9. Near-earth facilities configuration for *Lunar Orbiter*

Agency	Station	C-band radar	VHF telemetry	S-band telemetry
AFETR	Kennedy Space Center	X	X	X
	Cape Kennedy	X		
	Patrick AFB	X		
	Grand Bahama Island	X	X	X
	Antigua	X	X	X
	Ascension Island	X	X	X
	Pretoria, S. Africa	X	X	X
	RIS *Coastal Crusader*		X	X
	RIS *Sword Knot*	X	X	X
	RIS *Rose Knot*		X	
MSFN	Bermuda	X	X	
	Tananarive, Malagasy	X	X	
	Carnarvon, Australia	X	X	

Table 10. NASCOM circuit configuration for *Lunar Orbiter* to SFOF

Station	Teletype	Voice	High-speed data
Bldg AO	3	2	1
DSS 71	3	2	1
DSS 41[a]	4	1	1
DSS 51	3	1	—
DSS 62	4	1	1
DSS 12	4	2	1[b]
Bermuda	2	4	—
Tananarive	1	1	—
Carnarvon[a]	1	2	—

[a]For acquisition/coordination, one voice circuit was provided between DSS 41 and Carnarvon.
[b]6 MHz

(OCC) to assure that control of mission operations was exercised through the proper communications channels, and that LOP–DSN functions were understood by the personnel involved. During the 35-day critical period of the first two missions, this position of Supervisor of Network Operations was manned around the clock by the DSN PE and his assistants. After accumulating sufficient operational experience during the first two launches, the Supervisor of Network Operations (SNOMAN) position was deactivated and the various project and DSN operational elements interfaced directly with each other. The DSN advisors to the DSN PE were the same individuals who were members of the DSN PE's planning staff during the planning and implementation phases.

Line control of the DSN and the direct operational interface with *Lunar Orbiter* Mission Operations was performed by the DSN Operations Control Team. This team consisted of an OCC and an Operations Chief for each DSN Facility.

*2. **Mission-dependent equipment and operations organization.*** The *Lunar Orbiter* Project mission-dependent equipment (MDE) configuration and the associated DSIF interface are shown in Fig. 15. This equipment was used for telemetry bit detection and word decommutation of the telemetry bit stream for local display purposes, command message verification and/or generation, video reconstruction, and for film exposure. The MDE interfaced with the DSIF at the receiver and transmitter, and with the TCP Computer (Fig. 16). The *Lunar Orbiter* MDE operations organization and DSIF operational interface are shown in Fig. 17.

*3. **DSIF configuration.*** A standard DSIF S-band Tracking System, as shown in Fig. 18, was used to support the *Lunar Orbiter* Project. DSS 71, 41, 61, and 12 were designated as lunar support stations and were equipped with MDE. After the second launch, support was switched from DSS 61 to DSS 62. Two specialized pieces of equipment were introduced into the DSIF to support *Lunar Orbiter*. These were an FR 900 video tape recorder and an automatic antenna pointing system using an SDS 910 computer. The major DSIF operational functions were:

(1) To acquire ranging and doppler tracking data, and telemetry data; to generate and transmit commands.

(2) To format tracking and telemetry data for transmission to the SFOF via the GCF, and for operational use at the DSS.

(3) To record both telemetry and video data on analog and digital magnetic tape.

(5) To act as mission operations backup in the event of a communications loss with the SFOF. To provide a limited capability to control the spacecraft.

(6) To process exposed film.

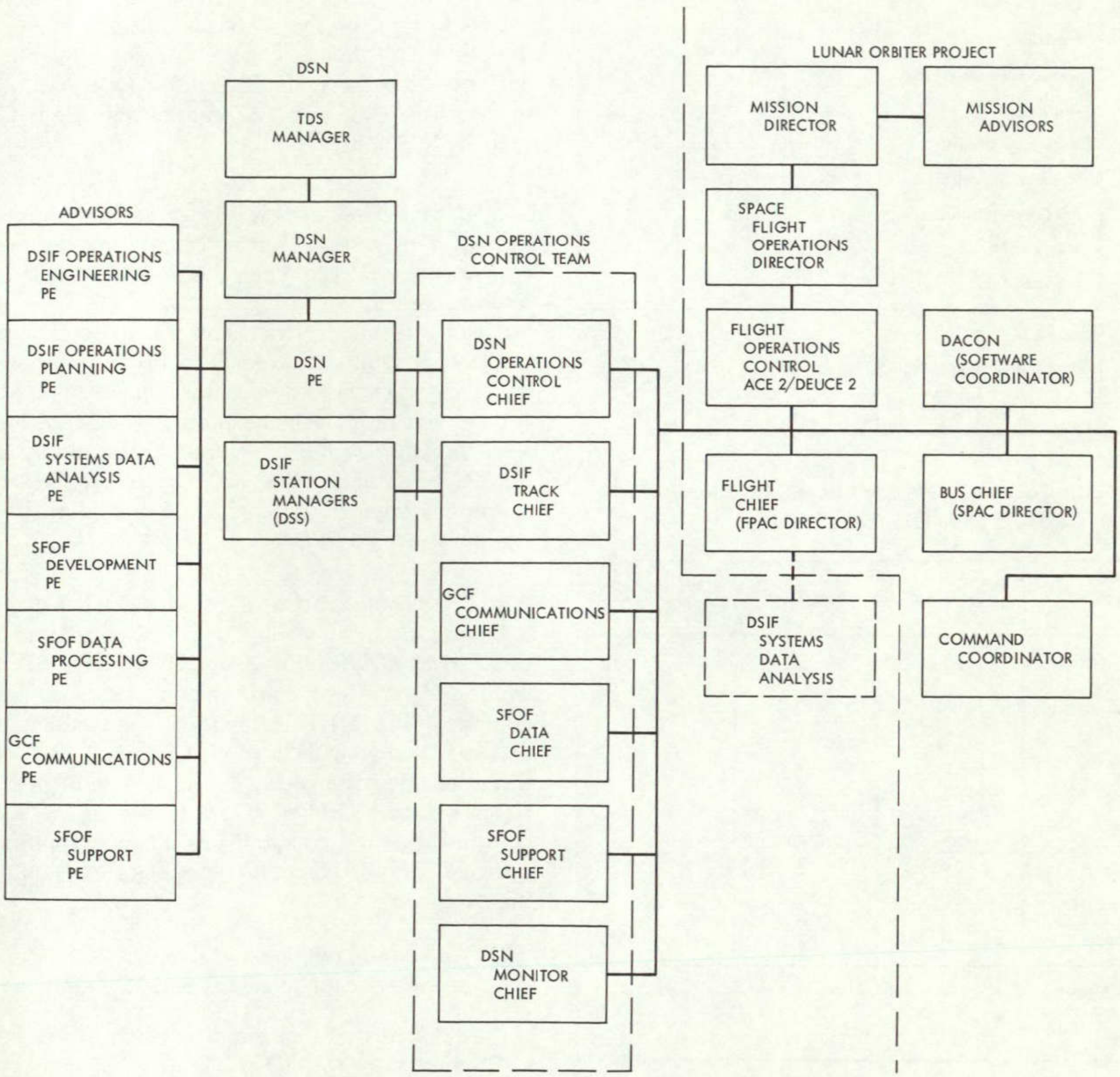

Fig. 14. DSN–*Lunar Orbiter* operations interface within the SFOF

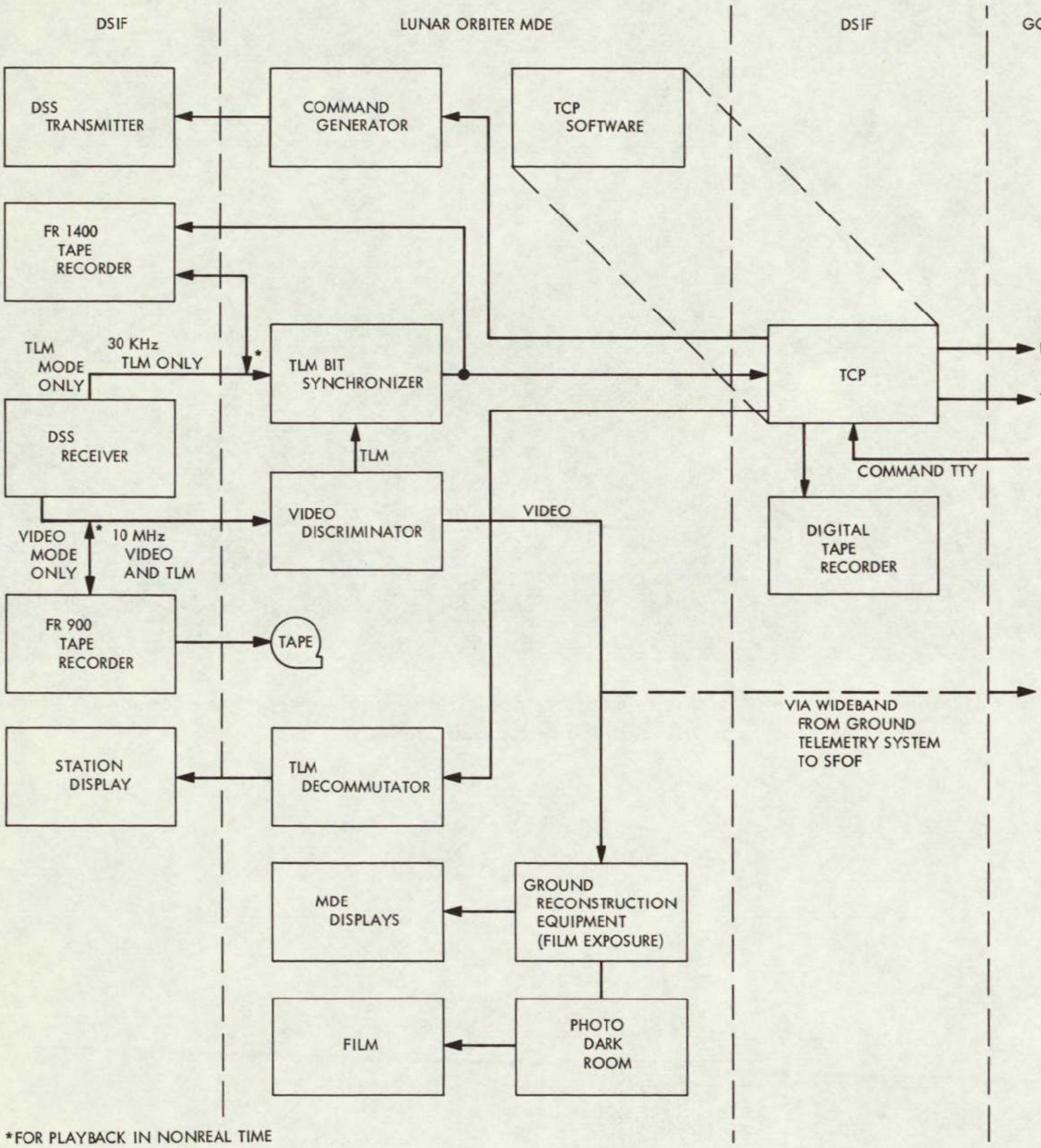

Fig. 15. DSIF–*Lunar Orbiter* mission-dependent equipment

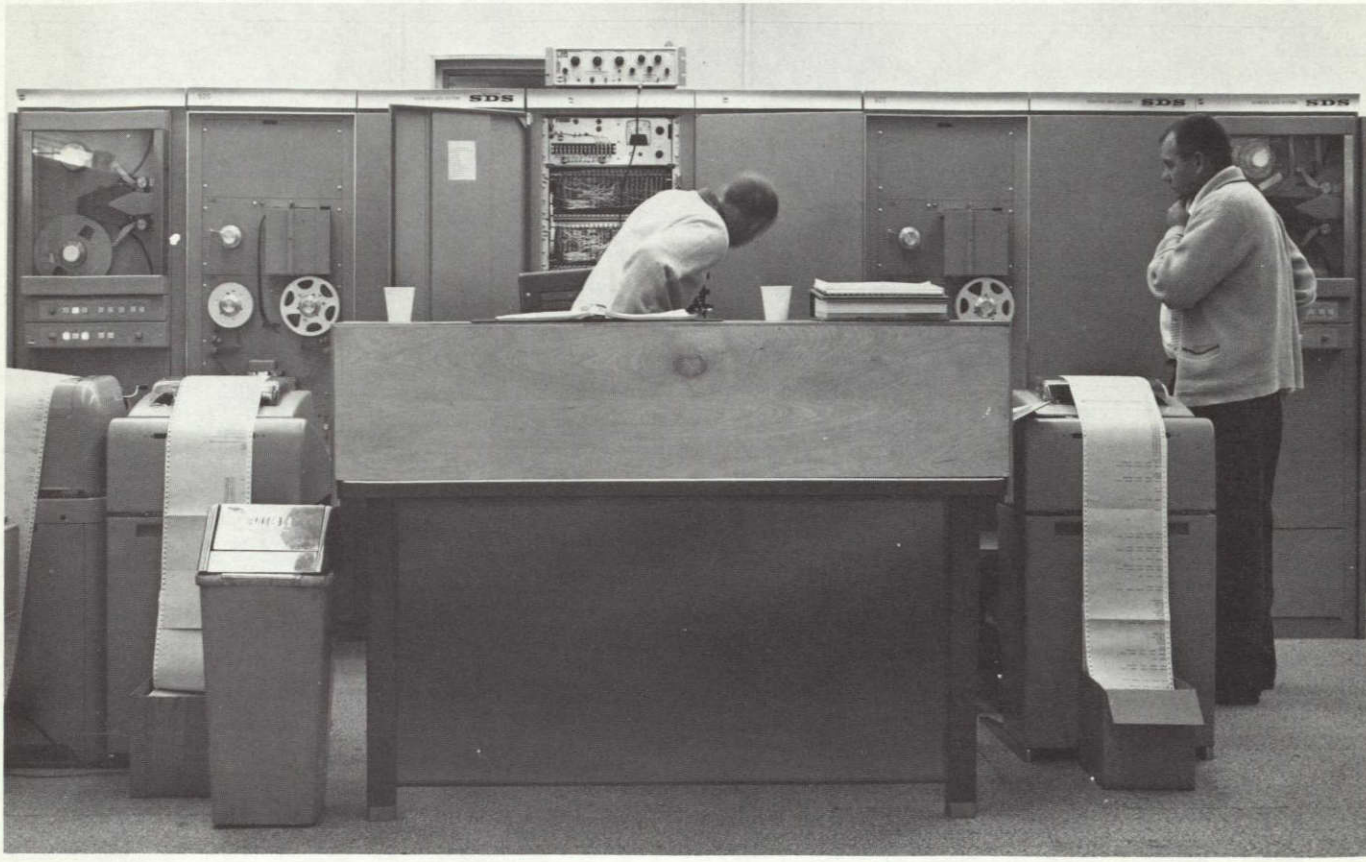

Fig. 16. Mission-dependent and telemetry and command data-handling computers for *Lunar Orbiter* installed at the prime DSIF stations

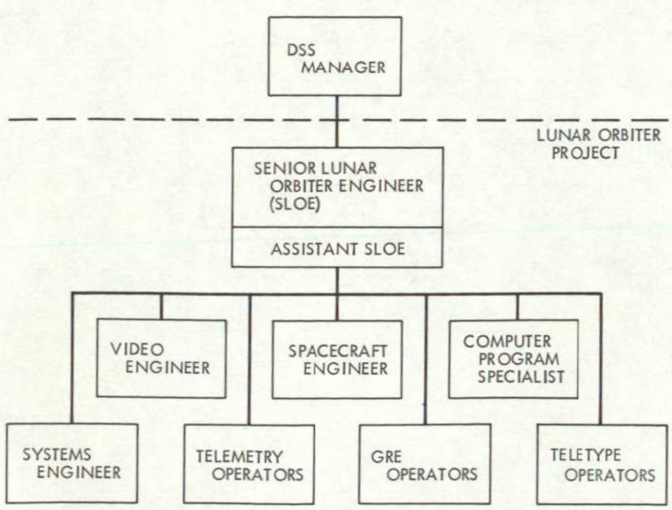

Fig. 17. The DSIF–*Lunar Orbiter* MDE operations organization

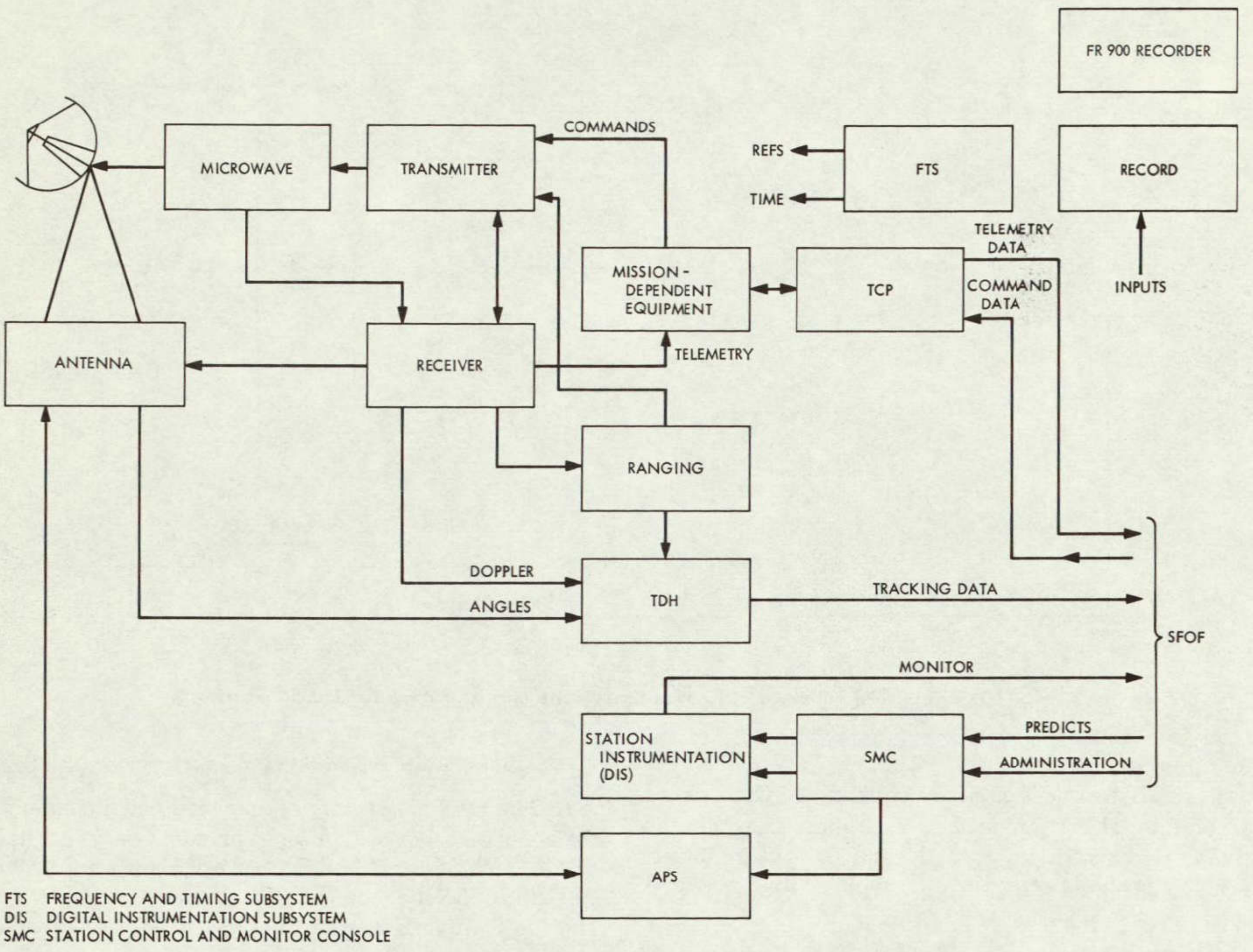

Fig. 18. The DSIF S-band tracking and communications systems

4. The GCF configuration. The GCF configuration for *Lunar Orbiter* is shown in Fig. 19. In addition to the standard teletype circuits and voice circuits used for project support, the GCF provided a new, high-speed data transmission capability. *Lunar Orbiter* telemetry was sent via high-speed data line from the DSIF stations directly to the SFOF Data Processing System (DPS). During the Goldstone view period, video data was transmitted to the SFOF for real-time monitoring of the spacecraft video system by Project personnel. The 6-MHz wideband microwave link between Goldstone and the SFOF was used to support this activity. Standard teletype circuits were used to transmit tracking data from the DSIF to the SFOF, and to transmit acquisition prediction information from the SFOF to the DSIF. Installation of the JPL communications processor (CP) during the LOP provided an automatic teletype switching capability for routing traffic to internal SFOF locations and to external locations. Command data were transmitted via teletype from the SFOF to the DSIF stations. Voice line support was provided during command operations.

5. The SFOF configuration. The areas assigned to the LOP are shown in Fig. 20. The SFOF configuration was designed to support three other space flight projects during the *Lunar Orbiter* support period. The configuration philosophy assumed that the Project mission analysis teams would interface directly with the central processor(s) via I/O equipment installed in the SFOF mission analysis areas. All mission analysis areas were dedicated to the LOP with the exception of the FPAC area which was time-shared with the other projects. The *Lunar Orbiter* Mission Control function was located in

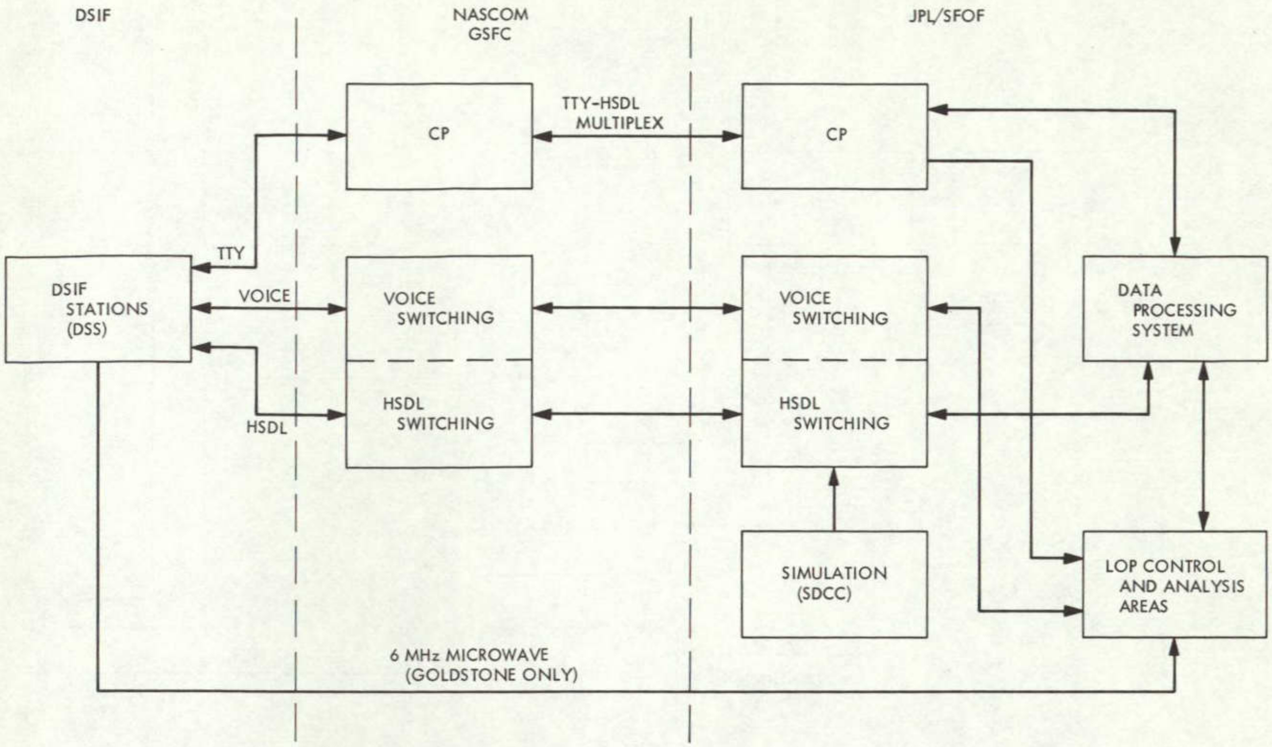

Fig. 19. Simplified DSN ground communications configuration for *Lunar Orbiter*

an area remote from the mission analysis area. The DSN–LOP operations interface within the SFOF is shown in Figs. 14, 21, 22, and 23. The data interface within the SFOF is described in Figs. 24 and 25. The following are the major operational and support functions provided by the SFOF:

(1) The DPS which consists of the Computer System (IBM 7044—1301 Disk—7094 computer string, including the software operating system and Orbit Determination Program), the I/O System (I/O consoles, printers, plotters, teletype displays located in *Lunar Orbiter* user areas), and the Telemetry Processing Station (processing of DSS analog telemetry magnetic tapes and real-time formatting of high-speed data line telemetry data for entry into the 7044).

(2) Mission analysis and control areas, including facility support of these areas for maintenance and minor reconfiguration.

(3) The SFOF operating personnel for multimission support functions.

(4) Data reproduction and library.

(5) Coordination of commissary and special parking facilities for mission operations personnel.

C. DSN Simulation and Monitor Support

1. The DSN simulation. A simplified flow diagram of the simulation system, showing the configuration of the SDCC, both System 1 and System 2, is shown in Fig. 26. The prime function of the SDCC was to support the DSN in certifying that all SFOF elements are capable of supporting the flight project. Simulated mission data are injected into the communications, data processing, and display interfaces to exercise hardware, software, procedures, and personnel at all levels throughout the DSN.

The *Lunar Orbiter* simulation activity for Missions I, II, and III was supported by the System 1 configuration (PDP-1 Computer) and was limited in capability. Subsequent premission tests employed the system 2 (ASI-6050 Computer) which had increased capacity and versatility. The SDCC was provided to the Project as a DSN-operated facility which included a standard SDCC operating software system. The requisite mission-dependent programs were supplied by the Project to interface directly with the standard operating hardware.

During Mission I, simulated tracking and telemetry data for the DSIF were prerecorded at the Boeing Company on FR 1400 tape recorders and sent by mail

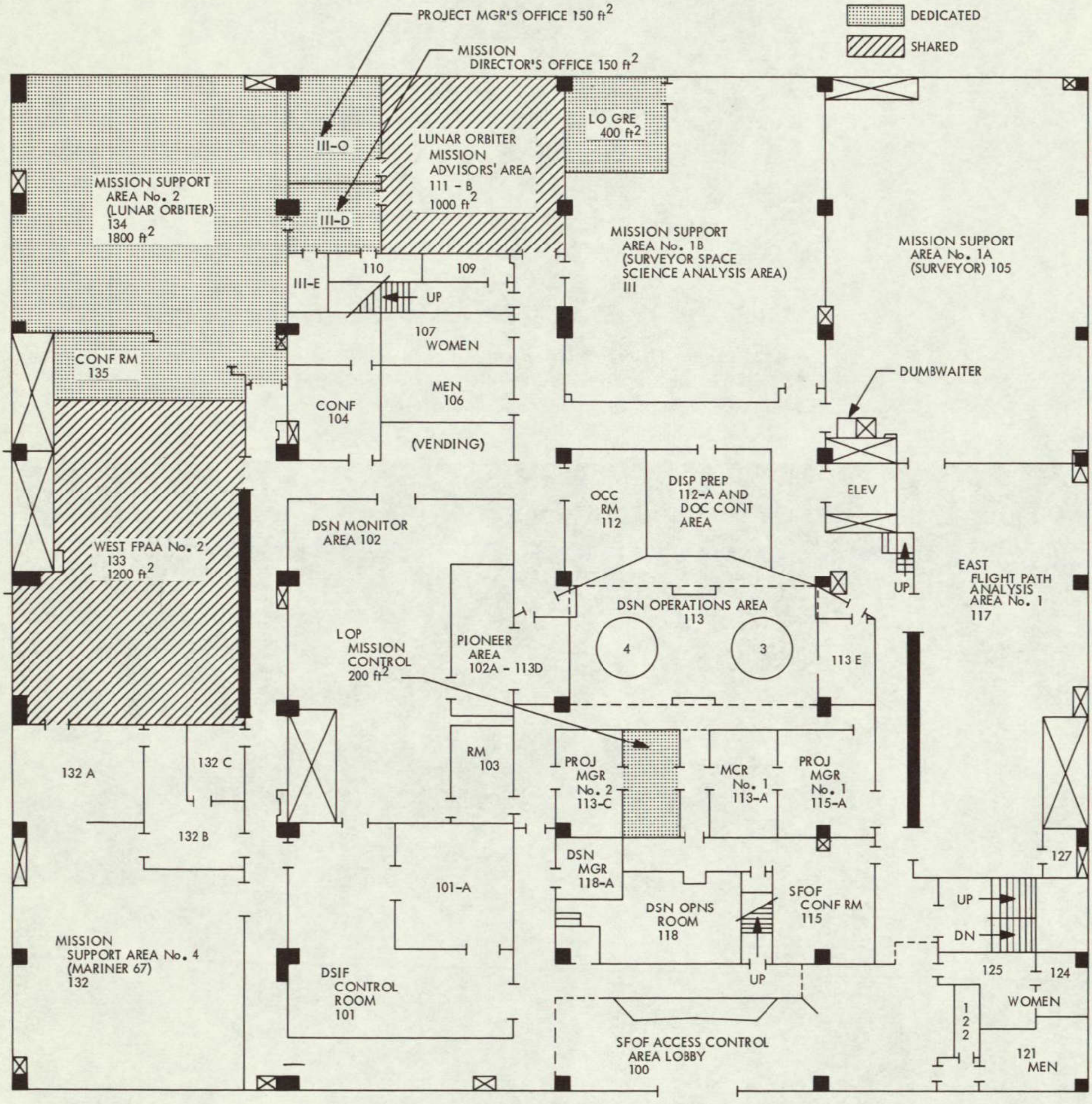

Fig. 20. The SFOF area configuration for *Lunar Orbiter*

Fig. 21. *Lunar Orbiter* mission control room in SFOF in Pasadena where spaceflight direction, spacecraft performance, and command operations were centered

Fig. 22. Orbital parameters posted in the joint Project–DSN FPAC area No. 2 in the SFOF, Pasadena

Fig. 23. Circular console in the SFOF DSN operations area. This position was used for launch and flight operations commentary to all NASA facilities

to the prime DSIF stations. For mission II and subsequent missions, simulated data were generated by the SDCC in the SFOF and sent to the DSIF stations via high-speed data lines (HSDL). In-flight spacecraft were also tracked to provide training for missions II through V.

The simulation exercises concentrated on spacecraft anomalies and the reaction to these anomalies by the mission analysis teams. The training of DSIF personnel through simulation exercises was minimal; DSIF participation was limited to the transmission of simulated telemetry data supplied on magnetic tape to the DSS or the "turnaround" of data supplied via the outbound high-speed data lines from the SFOF. These data were sent on cue and served mainly to exercise the GCF. The taped simulation data sent to each DSIF station were used primarily by on-site Project personnel and provided little, if any, mission-dependent training for the DSIF personnel.

Simulation exercises were made unduly complex by the lack of a unified test time base. Exercises were usually keyed to the nominal liftoff time of the upcoming mission; the DSIF stations, however, were not permitted to reinitialize station Frequency and Timing Subsystem

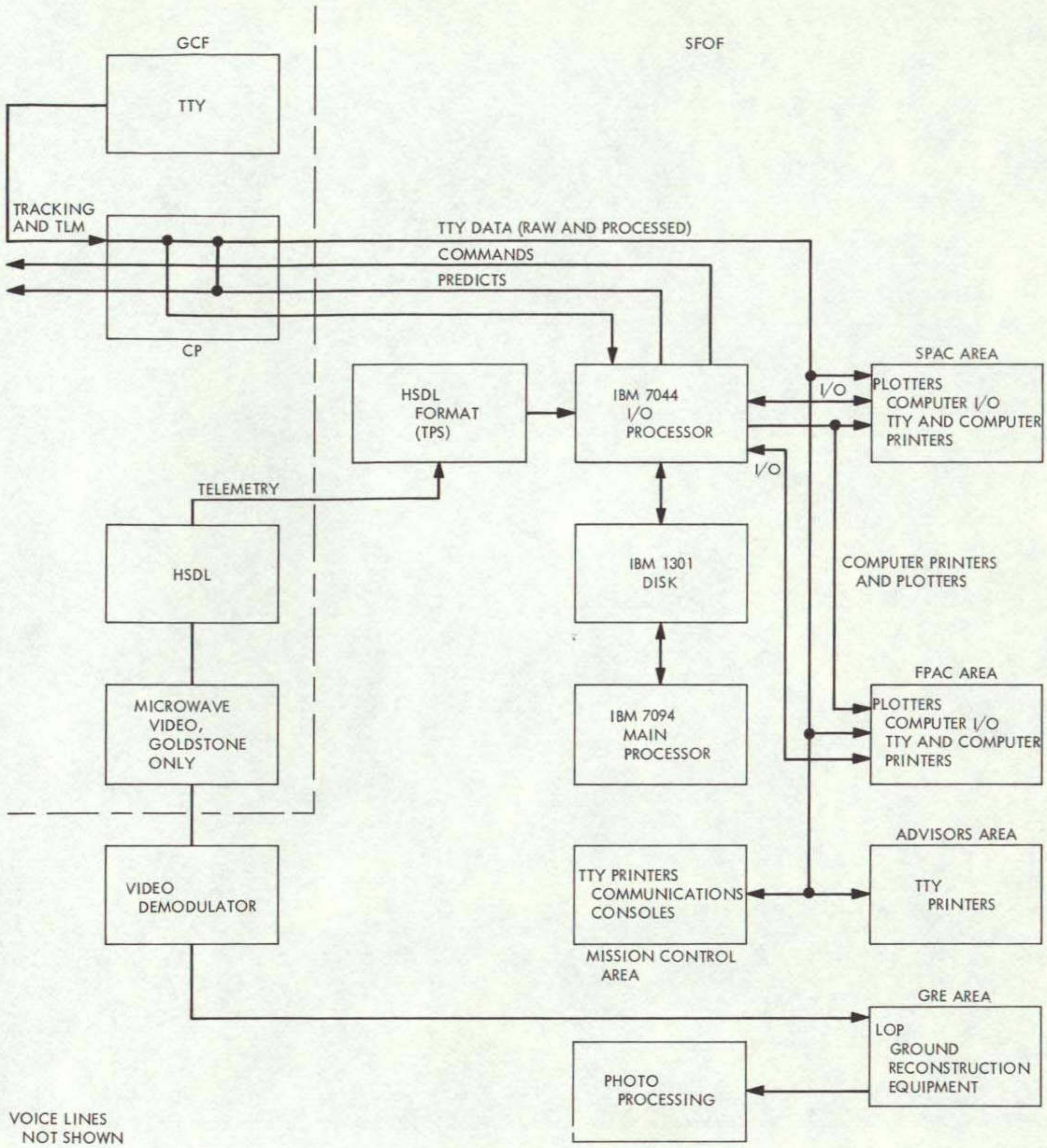

Fig. 24. The SFOF functional configuration for *Lunar Orbiter*

Fig. 25. The SFOF data processing area in Pasadena showing elements of IBM 7044/7094 computer string

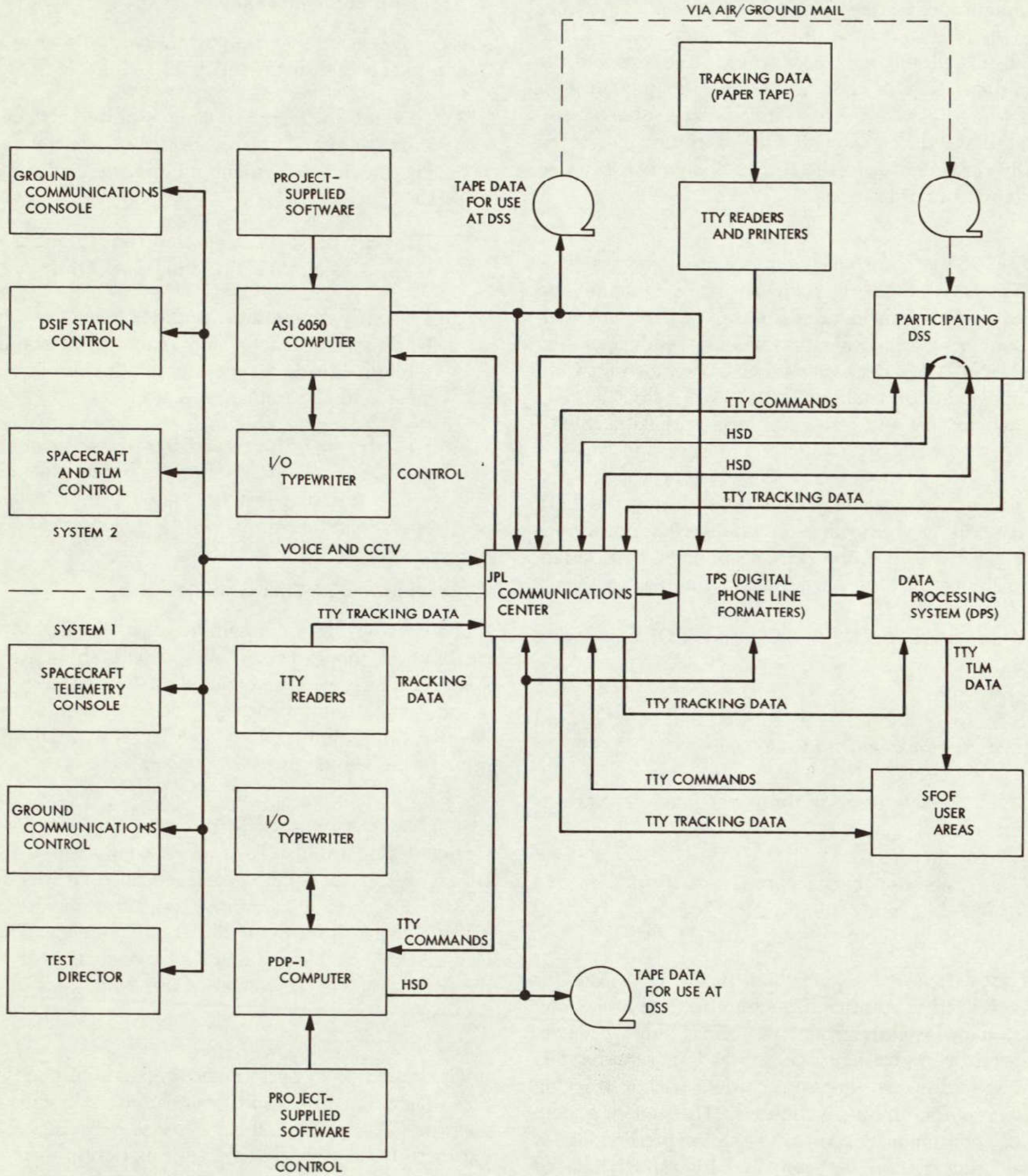

Fig. 26. Simplified SDCC data flow diagram

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(FTS) because of the attendant possibility of introducing timing errors into the operating system. At times, three different time bases were in use; each supported the simulation of a different mission system. These were the time-tags given to the simulation data, the real-time GMT displayed and referred to during the test, and the time system used in the printed mission sequence of events which was keyed to "launch time equals zero." Time displays throughout all DSN facilities had to be mentally converted to fit the test profile, which resulted in operator confusion.

2. The DSN Monitor System description and configuration. The DSN Monitor System consists of hardware and software that provide data and status displays for real-time monitoring and evaluation of the overall operation of the DSN. The system consists of a Monitor and Control Subsystem for each of the DSN facilities (DSIF, GCF, and SFOF) and a monitor area within the SFOF where data are displayed for monitoring and analysis by the DSN monitor team. The system was in the planning and early development stage during the LOP support period and provided only minimal support, representing a first step in the DSN Monitor System design. The functions performed by the Monitor System were:

(1) The collection of DSIF, GCF, and SFOF monitoring data.

(2) The reporting of overall DSN data quality and system performance in real time.

(3) The evaluation of performance against commitments.

(4) The generation of an alarm to warn of defective or lost data, and/or equipment failure.

The validation of tracking data by the DSN Monitor Team consisted of continuous monitoring of all incoming tracking data for correct teletype formats, and to detect gross errors or inconsistencies. Two teletype reperforators were operated in real time to provide a backup tracking data source for on-line computers. The tracking data were also continuously compared against predictions for determination of doppler noise and biases. High-speed telemetry data were displayed in the monitor area and checked for proper frame synchronization, identification, and format. The printer outputs were correlated with the backup teletype outputs to provide a check on the performance of the DPS and the GCF.

VI. TDS Compatibility, Verification, and Readiness Tests

A. Test Plan and Philosophy

The TDS testing to support *Lunar Orbiter* was designed to accomplish the following:

(1) To verify the technical compatibility between DSN subsystems and *Lunar Orbiter* subsystems, including mission-dependent equipment, software, and the spacecraft.

(2) To verify the TDS integrated configurations of the DSN, MSFN, AFETR, and NASCOM.

(3) To verify operationally the *Lunar Orbiter* and DSN systems data flow from data acquisition through the data processor to the display equipment and the human operator.

(4) To verify operational readiness of the *Lunar Orbiter* and DSN mission operations system, including a verification of personnel training and the level of operational performance.

B. Spacecraft-DSIF Compatibility Tests

Spacecraft-DSIF Compatibility Tests verified the compatibility of the spacecraft design with the appropriate DSS. The tests were conducted in two phases: (1) the design compatibility phase at Goldstone, and (2) the verification compatibility phase at AFETR with DSS 71 just prior to the launch of each spacecraft.

1. Design Compatibility Tests. Spacecraft–DSIF Design Compatibility Tests were conducted using the RF test facility at Goldstone. The spacecraft was located in an RF-tight screen room (Fig. 27) and RF-coupled via microwave links to an 85-ft DSIF antenna. The specific tracking and communications systems tested were the RF–Doppler, Telemetry, Command, and Ranging Systems.

The basic system performance was established through these tests; the test results were used as a standard to measure subsequent in-flight systems performance. During these tests, a ranging-system link-design discrepancy was detected which required a new definition of the Ranging System threshold.

2. Compatibility Verification Test. The Compatibility Verification Test constituted the final check by the DSN

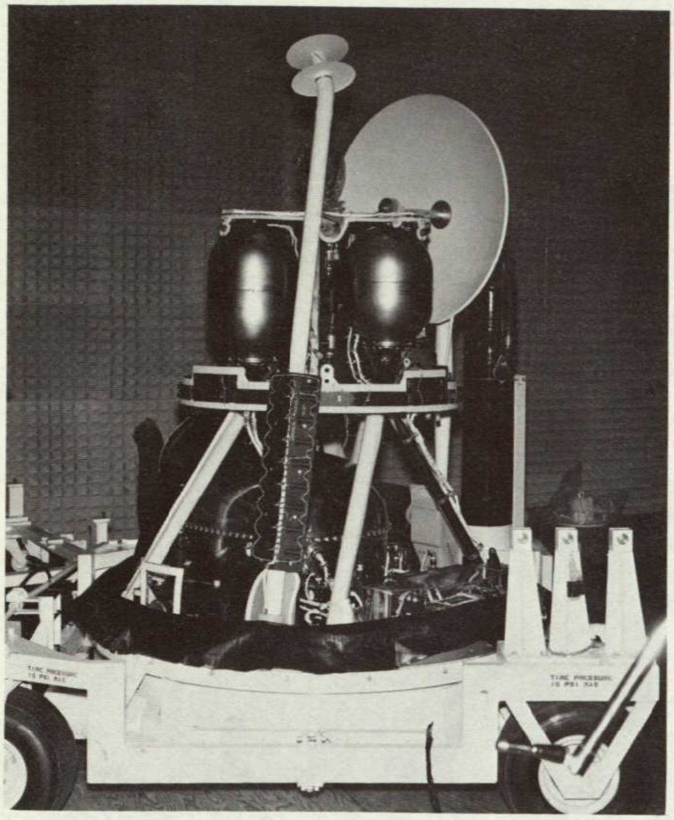

Fig. 27. *Lunar Orbiter* test model in RF test facility screen room at Goldstone. Tests established spacecraft–DSIF compatibility

and the Project that the spacecraft, in its final prelaunch flight configuration, was compatible with the DSIF configuration. The test was performed at DSS 71, the spacecraft monitor station at Cape Kennedy, Florida, shown in Fig. 28. An RF link was established between DSS 71 and the spacecraft and final performance parameters were measured and evaluated. Typical parameters tested were RF frequency stability, tuning range, RF threshold, RF spectrum, false lock points, etc. Telemetry, command, and ranging modulation were applied and verified for correct modulation characteristics and polarity. A significant error was discovered in the ranging system polarity during these tests when it was determined that the transponder subcontractor had not been instructed as to ranging system polarity requirements when the transponder was assembled. As a result, two out of the five *Lunar Orbiter* spacecraft had been assembled with reversed modulation polarity in the ranging channel. A minor change in the DSN Ranging Subsystem was made to accommodate this anomaly, since the Project did not desire to modify "flight accepted" spacecraft.

C. DSS MDE Integration Tests

The DSS MDE Integration Tests were conducted to demonstrate and verify DSS MDE hardware and software design compatibility in the following areas:

(1) Telemetry system performance.

(2) Video system performance.

(3) Command modulation performance.

(4) Software compatibility with the DSIF TCP computer.

(5) Local display of specific engineering telemetry parameters.

(6) Operational training level of MDE and GRE personnel.

(7) Throughput compatibility with the GCF HSDL.

D. Software Integration and Verification Tests

Software Integration and Verification Tests were conducted at both DSS and the SFOF to confirm the interface between *Lunar Orbiter* software programs and the DSN operating systems. The DSS tests were conducted as part of the MDE compatibility tests. The following types of software functions were verified:

(1) Capability for proper initialization.

(2) Capability for operating on any of the available data processors.

(3) Compatibility of all data modes.

(4) Compatibility with analysis area I/O and display equipment.

(5) Response to real-time simulated data generated by the SDCC.

(6) Detection of possible intercoupling of various routines on the processor.

(7) Compatibility with teletype and HSDL interface.

Because of changes to the previous mission software system, software integration and compatibility testing was required prior to each launch.

E. DSIF Operations Verification Tests

Operations Verification Tests (OVT) were required to verify the operational integrity and compatibility of each DSS with the GCF and SFOF operational interfaces.

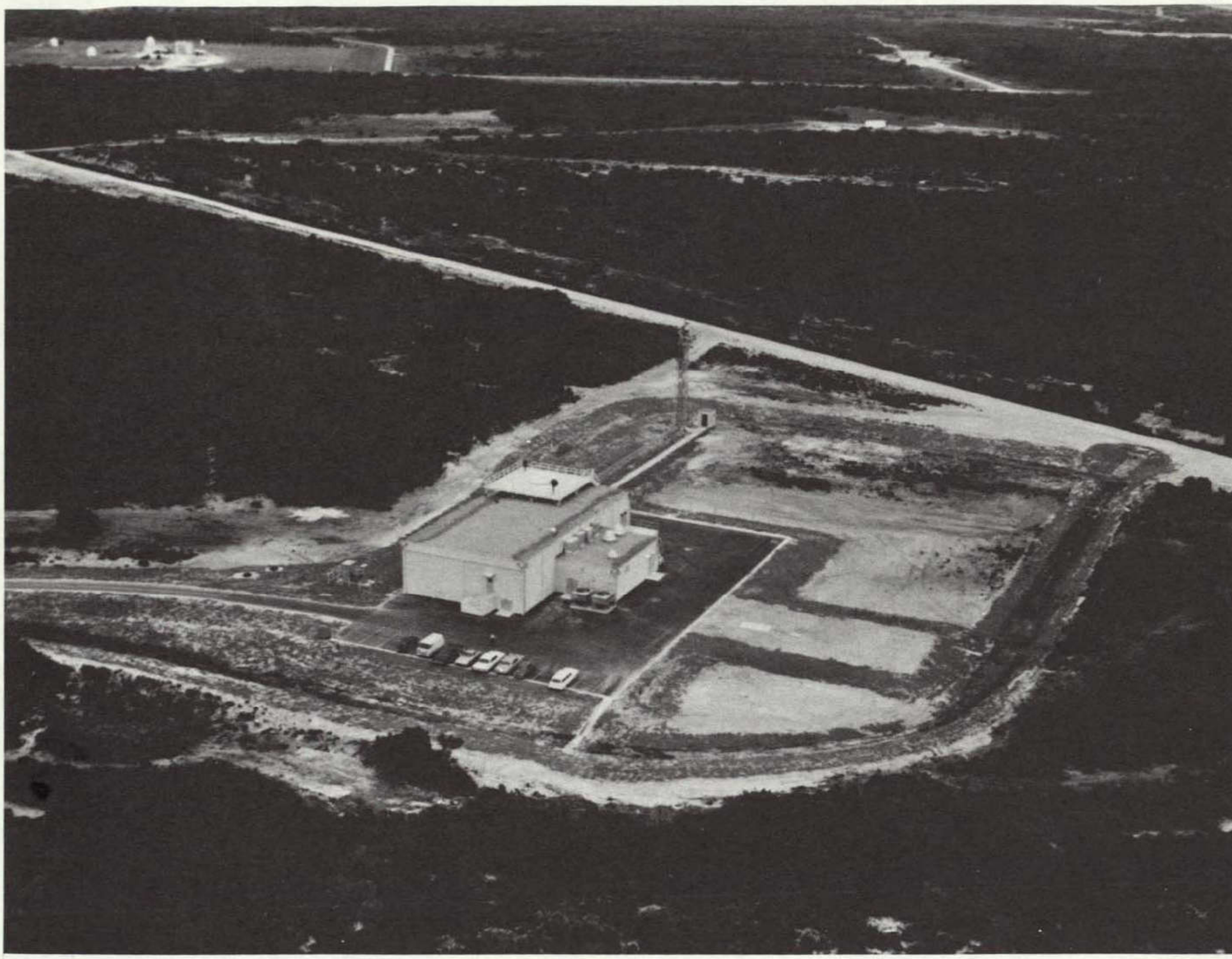

Fig. 28. Aerial view of DSS 71, the Cape Kennedy spacecraft monitoring station. Manually-pointed antenna for communication with the launch pad is on the roof of the building

The tests were conducted using simulated tracking, telemetry, and command data, and were designed to verify that the operating procedures in support of *Lunar Orbiter* were compatible with both the mission-dependent and mission-independent hardware and software systems, and that operational personnel were adequately trained in these procedures to properly support the mission.

F. DSN Combined Systems Tests

The DSN combined systems test involved the SFOF, DSIF, and GCF, and were designed to demonstrate (1) the end-to-end operational status of the *Lunar Orbiter* telemetry, tracking and command systems, (2) DSN–*Lunar Orbiter* ground data systems performance with simulated spacecraft data, and (3) total DSN readiness to support *Lunar Orbiter* operations.

G. Near-Earth Phase Testing

Near-earth phase TDS testing was limited to joint integration tests required to verify the systems and interfaces between two or more TDS support centers. These were performed as part of the ORT. Each Near-Earth Phase Center was responsible for executing its own internal test program preparatory to interagency testing to verify LOP commitments. Launch vehicle and spacecraft telemetry compatibility tests were conducted with AFETR stations prior to launch.

H. TDS Operational Readiness Tests

The ORT provided the final verification of the overall operational readiness of the TDS to support the near-earth and deep-space phases of the mission. These tests involved the entire system, including hardware, software, operational procedures, and interfaces between the TDS agency operating personnel. As a test model, various sections of the *Lunar Orbiter* mission sequence of events were exercised using simulated metric and telemetry data. Typical mission phases included in the test were launch, midcourse, lunar injection, and the photographic sequence.

VII. Support Summary

A. General

This section provides a general summary of the performance and support provided by the TDS during the five *Lunar Orbiter* missions. Project requirements and TDS commitments are compared with actual coverage and performance.

B. Near-Earth Phase Support

The support provided during the near-earth phase was consistent with mission requirements. Data outages did not compromise Project requirements or mission performance.

1. Required vs actual tracking and telemetry coverage. Required vs actual metric data coverage, launch vehicle VHF telemetry coverage, and spacecraft S-band telemetry coverage provided by the AFETR and MSFN may be found in Appendix B, Figs. B-1, B-2, and B-3.

2. Data processing and display. The AFETR RTCS performance during each of the five *Lunar Orbiter* missions was very satisfactory. The required early orbit determinations generated from MSFN and AFETR metric data were timely and accurate, relative to the quality of the received metric data and the speed of its arrival. Nominal spacecraft performance during the near-earth phase was confirmed during each mission. In virtually all cases, the DSS predictions generated by the RTCS were transmitted to the initial acquisition stations, DSS 51 and DSS 41, and to the SFOF within the nominal time period.

3. Ground communications. The near-earth phase ground communications configuration performed very reliably during each mission. Voice, HSD, and TTY circuits had a reliability of almost 100%, with the exception of the known variable performance of the high-frequency radio link to DSS 51.

C. Deep-Space Network Support

1. Metric data. The overall tracking system performance met Project metric coverage requirements (Table 4). An average of 95% of the real-time metric data was classified as acceptable and was made available to the Project at the SFOF. Metric data losses were caused by either momentary equipment malfunctions or by communications failures which resulted in garbled data transmissions. Tracking coverage by the DSN stations was better than 98% of the commitment to the Project.

Three *Lunar Orbiter* spacecraft were in orbit by Mission IV; all operated on the same frequency. This required the development of special acquisition and tracking techniques by the DSIF. To avoid sending commands to the wrong spacecraft, an offset frequency of approximately 33 kHz was used to command the desired spacecraft. Some difficulties were encountered, at first, with false locks on sidebands instead of the main carrier; very little data was lost, however.

The Mark I Ranging Subsystem performed without difficulty and results were very satisfactory. The data accuracy was better than the specified ±15-m capability, as determined by fitting ranging data points to trajectories integrated by doppler data alone. Ranging data proved very valuable for quickly reestablishing the spacecraft orbit after a motor burn. Use of the Ranging Subsystem for time correlation between DSN stations was provided to the Project and resulted in more accurate lunar orbit determination.

2. Telemetry and command. Both telemetry and command performance requirements were successfully met. Brief telemetry outages due to DSN station or ground transmission anomalies had no effect on spacecraft operations or mission control. In general, the TDS provided spacecraft telemetry data which exceeded class II requirements.

The basic Project requirement for the Command System was to maintain a continuous capability to transmit commands correctly to the spacecraft. The requirement was successfully met during each mission. Command operational and reporting procedures caused some ground operational difficulties during Mission I. Revised command procedures eliminated these problems during Mission II and subsequent missions.

3. Ground communications. The NASCOM and the GCF performed with a high degree of reliability during each of the five missions. The basic requirement to transmit data from the DSN stations to the SFOF was met. The reliability of HSD, TTY, and voice circuits was on the order of 95%, considering all outage phenomena. Telemetry was the only data type transmitted by HSDL from the stations, although the system is capable of sending metric data and DSS parameters. Communications satellite circuits were used in a backup capacity to carry voice, HSD, and TTY traffic during transocean cable failures.

4. Data processing and display. Data processing and display were considered both in the DSS and the SFOF.

a. Data processing in the DSS. The Project-supplied software for the on-site TCP performed well. The TCP computer interface with the Project-supplied MDE functioned smoothly and without problems.

b. Data processing in the SFOF. Considering its complexity, the *Lunar Orbiter* software system performed exceptionally well during all five missions, and remained essentially unchanged for the life of the Project. Minor corrections were made between missions, and modifications were necessarily added to adapt Project software to the newly installed NASCOM-compatible JPL CP. All high-speed data received from the Telemetry Processing System (TPS) and TTY data received from the JPL Communications Center were successfully processed by the IBM 7044/7094 computer strings, generally in Mode II (see Table 5). Display and I/O devices located in the user areas adequately fulfilled user requirements. The most significant problems experienced were SFOF power failures and numerous computer restarts. The restart problem was eventually traced to a wiring error in the IBM 7044/7094 communication line and was finally eliminated for Missions IV and V. Although these problems caused delays, all data was successfully processed in time to meet mission requirements. There were no software system failures.

5. Monitor System. The Monitor System was still under development at the beginning of the LOP and support for Mission I was not provided. Metric data for all missions was monitored and validated by the Systems Data Analysis (SDA) group. The new DSN Monitor Data System became operational for Mission II but was limited to telemetry data monitoring and validation. Support for Missions III, IV, and V included both telemetry and tracking data monitoring and validation, and the recording of real-time metric data on IBM cards as a backup tracking data source for the on-line computers.

Validation of metric data consisted of continually monitoring the incoming teletype data for (1) correct addresses and identification, (2) proper data format, and (3) gross data errors and inconsistencies. Metric data was also continuously compared against predictions for doppler noise and biases.

Validation of telemetry data consisted of continually monitoring the incoming data for essentially the same elements as the metric data. High-Speed Data (HSD) telemetry was displayed in the monitor area on bulk printers; the printer output was then compared with the TTY telemetry data as a check on the performance of the SFOF DPS and the GCF. Table B-2 in Appendix B provides a summary of metric and telemetry data validated by the monitor team.

The monitor team also maintained a status board which indicated the current DSIF station tracking status and station performance.

a. Mission I. The DSN monitor team had not yet achieved operational status and did not support Mission I. Tracking data validation was performed by representatives of the DSIF SDA group. The telemetry data monitoring function was limited to verifying that a data stream was passing a given monitor point in the DSN system and that all DSN equipment were operating within tolerance.

b. Mission II. Mission II was used primarily to train and familiarize monitor personnel with DSN and mission operations. Support was limited to TTY telemetry data validation over a 31-day period from $L-6$ h to the end of the photographic mission. The DSIF SDA group retained responsibility for metric data validation.

c. Mission III. The monitor system support was expanded to include tracking data along with TTY telemetry data monitoring and validation. Monitor support was limited to an 18-day period due to construction and development activities in the monitor area which prevented further activity.

d. Mission IV. Mission IV support included HSD telemetry monitoring along with TTY tracking and telemetry data. High-level multimission activity limited monitor support for Mission IV to $L+16$ days. Backup tracking data was punched on IBM cards only during the mission-critical phases (launch, midcourse, and lunar injection).

e. Mission V. Monitor support for Mission V was essentially the same as for Mission IV, except that operations were supported from launch through the end of the photographic mission.

6. The DSIF predicts. With few exceptions, DSIF tracking data predicts were generated and distributed to the DSIF stations in a timely manner. The overall quality of the predicts generated for the cislunar phase was good. Predicts generated during the lunar orbit phase were found to contain inaccuracies and became a major problem during the earlier missions. Errors were particularly noticeable in lunar orbits with low periseleniums, and were traced to inaccuracies in the lunar model which did not compensate for lunar harmonics. Because of the model deficiency, good lunar injection conditions were difficult for the Orbit Determination Group to calculate; initial errors were consequently produced which caused the accuracy of the doppler predicts to degenerate, typically in excess of 100 Hz over a 2-day period. As knowledge of the lunar harmonics increased with each mission, the problem was diminished but was never totally eliminated. Although DSIF acquisition of the spacecraft was seldom affected, the inaccuracies made it necessary to frequently generate new predicts and significantly impaired the usefulness of the Tracking Data Monitor Program (TDM) which compared tracking data with predictions and calculated doppler biases and noise.

D. Major Facility Changes During the *Lunar Orbiter* Project

1. DSN changes. While AFETR and MSFN facilities remained unchanged during the LOP, four major changes to DSN facilities were made.

A major change to the configuration of the GCF was effected by the scheduled changeover in the JPL Communications Center to a Communications Processor Switching System. Missions IV and V used the hardwire teletype system during major testing and the launch phase, then were switched through the CP during lunar orbit. The extended phases of Missions IV and V were fully supported by the CP. The CP installation forced the Project to change their software interface with the GCF teletype system.

Between Missions II and III, the DSIF prime *Lunar Orbiter* support station in Spain was changed from DSS 61 to DSS 62. The change was made necessary by modifications to DSS 61 which were required for support of the *Apollo* Project. In addition, the FPAC area in the SFOF being used by *Lunar Orbiter* was reconfigured to accommodate the *Mariner V* program during this period.

Prior to Mission V, the mission display in the SFOF operations area was reconfigured. The main impact of this change was the noise generated by the construction activities.

2. Project change requests. During the time period from October 6, 1965 to October 4, 1967, a total of 2229 change requests were submitted to the DSN by flight projects. Of this number, 20.9%, or 466 change requests were submitted by the LOP. The most significant of these changes were:

(1) Installation of a GRE area adjoining the *Lunar Orbiter* advisors area which was used for near-real-time photo evaluation by the Project.

(2) Installation of additional teletype displays in the Project Mission Control area; these were used to provide improved coordination of spacecraft command procedures.

E. TDS Failure Reporting System

Hardware, software, and procedural problems or failures which occur in any of the DSN facilities during a test or a mission are reported by the observer via the DSN Discrepancy Reporting System (DRS). The system provides a controlled, centralized method for systematically documenting and correcting all operational problems and failures while at the same time provides the TDS with visibility into overall DSN operational readiness and performance.

A listing of discrepancy reports generated against the DSIF during each mission and a partial listing of discrepancies reported against the SFOF DPS and Intracommunications System (ICS) during Missions III, IV, and V will be found in Appendix B, Tables B-3 and B-4, respectively. Discrepancy report totals per spaceflight project and per *Lunar Orbiter* mission are given in Tables B-5 and B-6.

F. Mission Support Man-Hours and Facility Loading

1. The SFOF loading. Table C-1 summarizes the loading of SFOF systems and areas during Missions I through V. The Operations Control Chief (OCC) scheduling effort represents real-time rescheduling and the percent of scheduling effort required for *Lunar Orbiter*. The "Percent LO Operations" figures represent the percent of operations performed and not time used. Operational time percentages, as represented by DPS and SDCC utilization, are presented in Figs. C-1 and C-2. The DSIF hours in Table C-2 cover only the photographic missions. Other data are to the nearest week.

Graphic presentations of DPS and SDCC utilization during major testing and the photographic mission periods are shown in Figs. C-1 and C-2. Utilization of the IBM 7094 main processor only is shown in Fig. C-1; IBM 7044 information is not included since its utilization closely followed the IBM 7094. The $L - 18$-wk period for Mission I is also included since the major portion of training, testing, and development for all missions took place during this time. Data sources are the DSN utilization summaries, the DPS utilization reports, and the "as used" bar charts kept by the SDCC.

2. The DSIF loading. DSIF loading is presented in Table C-2 and is expressed in hours expended for tracking, Operational Readiness Tests, and pre/post calibration time.

3. The GCF loading. The GCF loading, in terms of hours of use, is not listed separately but follows closely the DSIF loading in Table C-2, exclusive of the pre/post calibration time. Generally, the circuit requirements for each prime DSIF station consisted of four TTY circuits, one voice, and one HSD circuit. See Fig. 19 for circuit particulars.

4. The SFOF man-hours. Table C-3 lists estimated SFOF man-hours used during the prelaunch and photographic phases of each mission. The man-hours listed are only an estimate due to a combination of multimission activity and the limitations of the SFOF reporting system in use during the LOP. The estimates are derived from SFOF TPS usage, DSIF support activity, and other data listed in Table C-3.

5. The GCF man-hours. The JPL Communications Center supported the five *Lunar Orbiter* missions with 17,700 h of straight time and 2,397.5 h of overtime. Table C-4 lists Communication Center man-hours used on a per mission basis.

6. The DSIF man-hours. Table C-5 lists the total man-hours expended by the DSIF on a per mission basis.

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Part II. *Lunar Orbiter I*

I. Introduction

A. Mission I Objectives

The primary overall objective of the *Lunar Orbiter* Project was to search for and survey acceptable lunar landing sites for the *Apollo* Project. An additional objective during this first mission was to obtain sufficient tracking data during an initial high-lunar orbit in order to gain more precise information about lunar gravitational harmonics. This information, in turn, was used to determine acceptable long lifetime low orbits for lunar photography. Selenodetic measurements were continued through the end of the mission.

B. Mission I Summary

Mission I was originally scheduled for launch early in July 1966. Because of spacecraft performance problems, however, the launch was rescheduled for an early August opportunity. The spacecraft was subsequently launched from Complex 13 at Cape Kennedy at 19:26:00.716 GMT, August 10, 1966, on a flight azimuth of 99.9 deg. Preliminary analysis of AFETR tracking and telemetry data indicated very satisfactory performance by the first and second stage vehicles. After a predetermined coast period in the parking orbit, the *Agena* second-stage vehicle was restarted and injected into its cislunar trajectory. The spacecraft then separated from the *Agena* stage and began its initial operation by initiating the automatic solar acquisition sequence. The first of two planned midcourse maneuvers was performed on August 11, 1966. This first orbit correction was sufficiently accurate so that a second maneuver became unnecessary. After 92 h of cislunar flight, the spacecraft was injected into an initially high lunar orbit and tracked for several days to provide the necessary data for analysis of the lunar gravitational effect. The spacecraft was then injected into its low photographic orbit. Lunar photography began on August 18, 1966, and continued through August 29, 1966. The DSN tracking was terminated on October 29, 1966.

All requirements placed on the TDS for support of Mission I were met and, in many areas, exceeded.

II. Preflight Readiness

A. General

The preflight readiness of the TDS was established by means of DSN compatibility, verification, and readiness tests, a DSN readiness review and a near-earth phase readiness review. The reviews were held 2–3 wk prior to launch and were organized to determine the capability of each TDS element to support the mission, to specifically identify and discuss any existing or anticipated problems, and to establish a schedule for their resolution. The results of these reviews were then submitted by the TDS Manager to an overall Flight Readiness Review which was conducted by the LOP at Cape Kennedy.

B. Preflight Tests

Preflight testing for Mission I proceeded in accordance with the test plan and philosophy described in Part I, Section VI, of this report.

1. Spacecraft–DSIF Compatibility Tests. Spacecraft–DSIF design compatibility tests were conducted with the proof test model of the spacecraft (spacecraft C) installed in the spacecraft test facility at Goldstone. The Mission I flight spacecraft was shipped to DSS 71, Cape Kennedy, where compatibility verification tests to confirm design compatibility with the DSIF configuration were performed between July 28 and August 2, 1966.

2. The DSIF–MDE Integration Tests. MDE integration and DSIF engineering verification tests were conducted during July 1966, with DSS 12, 41, 61, and 71. The video tape recorder, the telemetry and command MDE, and the GRE were all exercised and operated satisfactorily. During the course of the tests, it was anticipated that factory technicians would be required at the stations to maintain the video tape recorders. Use of special FR 900 magnetic tape was also initiated to provide longer recording head operating life.

3. Software Integration and Verification Tests. Compatibility tests of Project software analysis programs and DSN operating system software were conducted at the DSIF stations and the SFOF. The software was "frozen" before the first operational readiness test and placed under firm change control procedures.

4. Near-Earth Phase Test. Near-earth phase testing was performed to support the TDS operational readiness tests. The AFETR commitments for VHF and C-band radar coverage remained tentative because all launch azimuths could not be covered with the number of RIS provided. Other problem areas subsequently resolved were:

(1) Methods for postlaunch verification of the quality of S-band compatibility test tapes.

(2) Resolution of differences between targeted trajectory data (Firing Tables) and conic approximations used in the AFETR computers. This involved recomputation of AFETR station coverage commitments with limited time before launch.

(3) Firm definition of spacecraft telemetry modes, mode sequences, and modulation indices.

(4) Project requirements for real-time Channel F telemetry transmission from Tananarive (spacecraft telemetry via launch vehicle telemetry transmitter).

(5) The DSN–AFETR interface for DSN FPAC orbit determination purposes was determined to be satisfactory for standard mission performance but unsatisfactory in response to possible nonstandard performance. Additional simulation tests were conducted to improve this area.

5. TDS Operational Readiness Tests. Combined system tests of the AFETR, MSFN, NASCOM, and DSN were conducted satisfactorily. End-to-end data flow configurations were tested using simulation data provided by the Project. The use of different time bases for the spacecraft, the AFETR, and the DSN did not allow the simulation of a centrally controlled, coordinated countdown for all mission systems.

C. DSN Readiness Review

The first DSN Readiness Review for Mission I was held at JPL on June 16, 1966, in preparation for a scheduled July launch. A normal variety of equipment and operational problems involving both the Project and the DSN were discussed. The more important problem areas were:

(1) Determination of spacecraft transponder temperature vs frequency characteristics to be provided by the Project to the DSN so that acquisition predicts which are based on these characteristics would be sufficiently accurate.

(2) Reestablishment of policy for the use of IBM 047 paper tape-to-card converter as a backup source for metric data.

(3) Establishment of launch constraints imposed by maximum doppler limitations of the DSS 41 receiver for the first two days of the August launch opportunity.

(4) Completion of the FR 900 tape recorder compatibility and checkout procedures at the DSS.

(5) Establishment of a DSN–Project software change control procedure.

Subsequent to the June 16 review, a spacecraft problem developed which necessitated rescheduling the launch from mid July to an August 9–14 launch opportunity. A second DSN Readiness Review was held at JPL on July 22, 1966. All prior action items were discussed and their close-out dates confirmed.

The DSN confirmed its readiness to support an August launch provided the following mandatory tests and/or training were completed prior to launch:

(1) Two RF tests with the spacecraft in the explosive safe area, one before encapsulation and one afterward.

(2) DSIF station reverification tests.

(3) Additional SFOF personnel training.

(4) Completion of a successful Project ORT.

D. Near-Earth Readiness Review

The first Near-Earth Readiness Review was held at Patrick AFB, Florida, on June 21, 1966. The second review was conducted by telephone conference in conjunction with the DSN Readiness Review on July 22.

1. The AFETR support. Resolution of action items from the June 21 review involving normal problem areas was presented. The significant items were:

(1) Commitments for VHF telemetry and C-band radar coverage would be subject to revision based on coverage restraints for certain launch azimuths. Repositioning of the range instrumentation ships (RIS) was expected to improve conditions.

(2) Radio interference and propagation difficulties with RIS HF communications.

The Project agreed to launch under these marginal conditions. An item of particular concern was the status of the RIS *General Arnold* which had failed to receive metric, VHF, and S-band data during the launch of *Surveyor I*. The previous performance notwithstanding, the RIS *General Arnold* was assumed to be capable of supporting *Lunar Orbiter* with VHF telemetry, S-band telemetry, and metric data.

2. The MSFN support. Resolution of problem areas discussed at the June 21, 1966 review was presented as follows: a statement had been requested from the Project regarding the need for real-time spacecraft data via the launch vehicle VHF (Channel F) telemetry from Tananarive since no HF ground communications capability from Tananarive existed. In answer to the Project's affirmative request for these data, the transmission of Channel F data would be attempted using an HF voice link to Cape Kennedy via the NASA Goddard Space Flight Center (GSFC). Priorities for the use of this line for this purpose were requested.

E. Communications Support Readiness

1. The NASCOM. The GSFC reported NASCOM ready to support Mission I. Tests were scheduled with AFETR to confirm whether or not Channel F spacecraft data could be transmitted from Tananarive in real time.

2. The DSN GCF-ICF. All GCF and SFOF communications circuits were reported green and ready to support an August 9–14 launch.

III. Near-Earth Operations and Performance Summary

A. Countdown Summary

The countdown included two built-in holds (BIH) consisting of a 50-min hold at $T - 60$ and a 10-min hold at $T - 7$ min. The AFETR countdown started at 09:53 GMT on August 9. The $T - 7$ BIH was extended because of an *Atlas* propellant utilization system problem, and the launch was subsequently scrubbed at 19:30 GMT. The count was resumed on August 10 at 11:01 GMT and proceeded smoothly. At $T - 35$ min, the count was held for 13 min to accommodate an *Agena* fuel tank pressurization problem. The count was resumed at 18:39 GMT and proceeded through the $T - 7$ BIH which was extended an additional 3 min to change flight azimuths. Liftoff occurred at 19:26:00.716 GMT, on a flight azimuth of 99.9 deg. The near-earth support station configuration for Mission I is shown in Fig. 29.

B. AFETR Performance

1. C-band metric data. Committed vs actual metric coverage is shown in Fig. 30. All metric requirements were met except for the RIS *General Arnold* which had difficulty in maintaining metric track and obtained a total of only 92 s of combined radar beacon and skin track data. The problem was traced to a primary power source shared by both the vertical transmitter used for

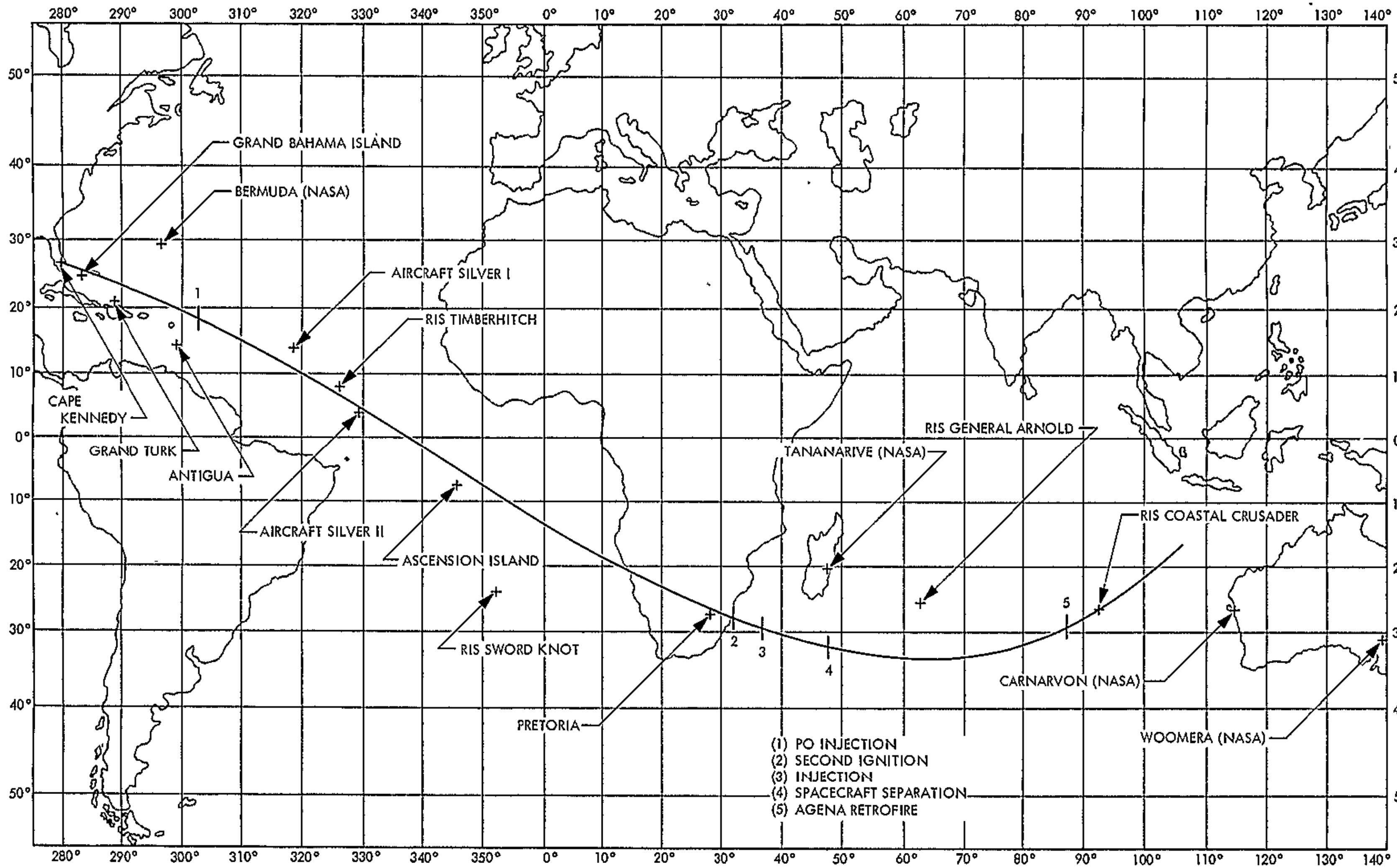

Fig. 29. Mission I near-earth support station locations

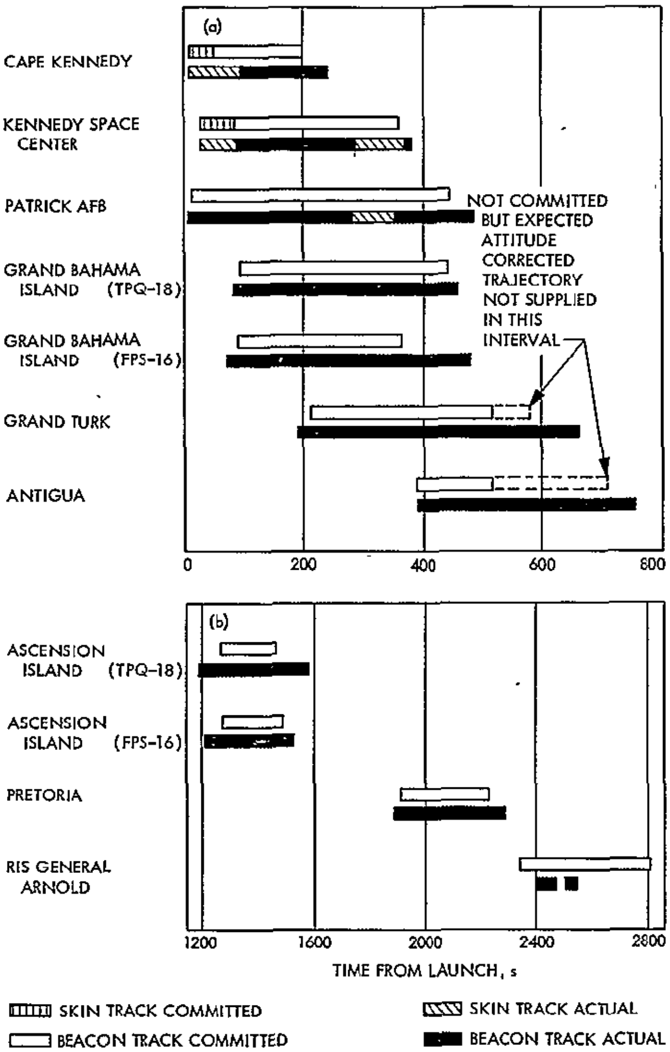

Fig. 30. Mission I AFETR radar metric coverage

C-band radar skin tracking and the horizontal transmitter used for beacon tracking. VHF and S-band telemetry data received by the RIS *General Arnold* were unaffected.

2. ***The VHF and S-band telemetry data.*** Expected vs actual VHF and S-band telemetry coverage is shown in Figs. 31 and 32. Spacecraft telemetry received via the 98 kHz subcarrier (Channel F) on the *Agena* telemetry link was successfully retransmitted from receiving AFETR stations through Cape Kennedy Tel-2 to DSS 71 and then to the SFOF in Pasadena. Channel F data were selected and switched to DSS 71 from the various downrange stations at the times listed in Table 11. All telemetry requirements were met by the committed land stations, two telemetry aircraft, and RIS. Equipment problems that affected coverage were:

(1) The Cape Kennedy Tel-2 S-band antenna experienced a data dropout due to a faulty bearing which caused the antenna to stick in the vertical position.

(2) The Pretoria S-band antenna was blocked by the VHF antenna structure, resulting in the loss of approximately 2 min of S-band data during the view period.

3. ***The RTCS data processing.*** Computations performed by the RTCS and the time of the computation are listed in Table 12. All computation requirements were met and predicts for the DSIF stations were generated on time. The handover of the processing responsibility to the SFOF at the end of the near-earth phase was accomplished smoothly. In addition, the RTCS provided dual

Table 11. *Agena* Channel F spacecraft telemetry received at DSS 71 for retransmission to the SFOF

Station	From, GMT	To, GMT	Total frames	Usable frames	Usable, %
Cape Kennedy	19:26:00	19:27:10	3	3	100
Grand Bahama Island	19:27:10	19:33:30	16	13	81
Antigua	19:33:30	19:38:49 (LOS)	13	7	54
Ascension Island	19:46:34 (AOS)	19:52:58	16	15	94
RIS *Sword Knot*	19:52:58	19:57:53	13	11	85
Pretoria	19:57:53	20:01:20	9	6	67
Tananarive	20:01:20	20:05:29	10	10	100
RIS *General Arnold*	20:05:29	20:06:48 (spacecraft separation)	3	1	33

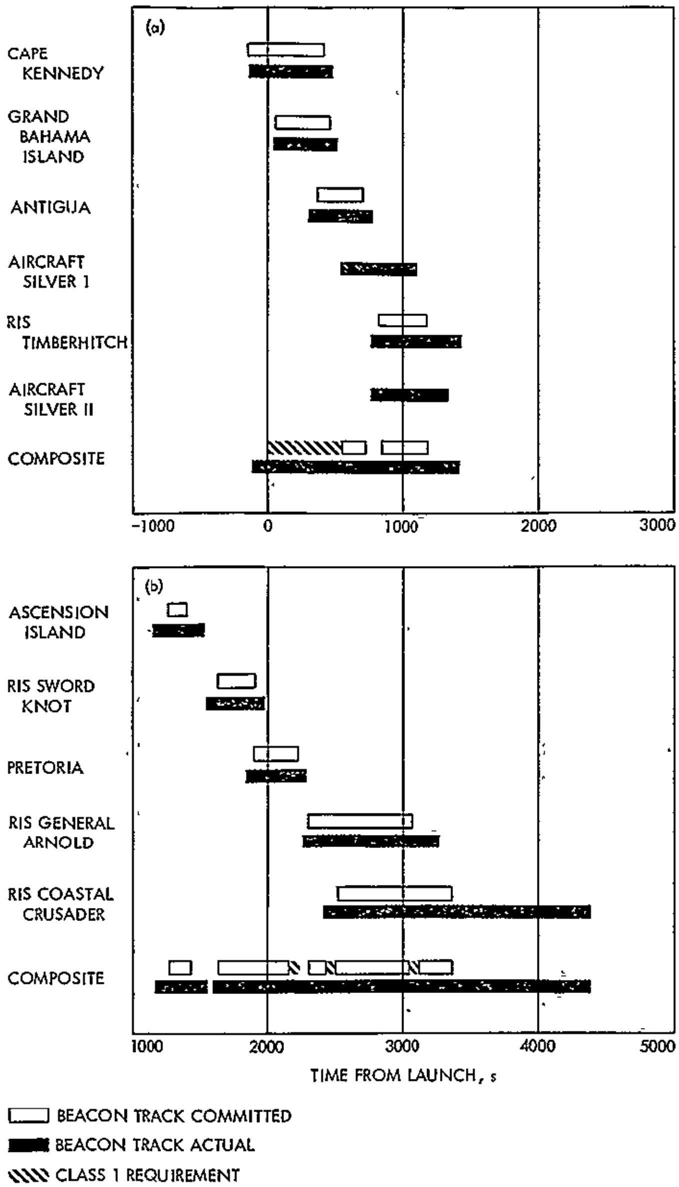

Fig. 31. Mission I AFETR VHF 244.3 MHz telemetry coverage

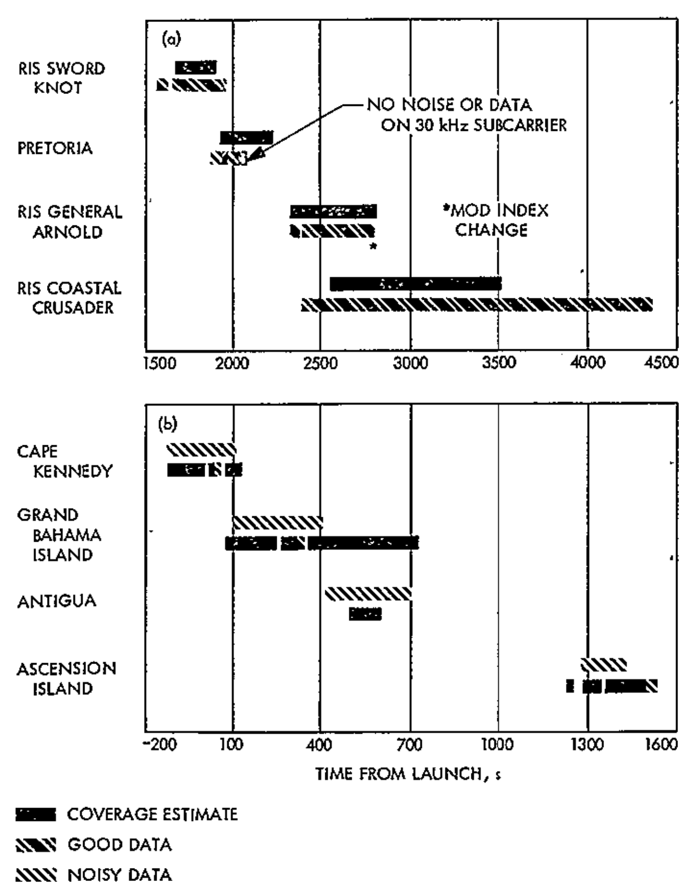

Fig. 32. Mission I AFETR S-band telemetry coverage

Table 12. AFETR Real-Time Computer System performance

Time from launch, min		Computation
Nominal	Actual	
4	4	Liftoff message
17	12	Parking orbit (PO) IRV, standard orbital parameter message (SOPM), orbital elements
22	15	Tananarive and Carnarvon look angles (PO)
22	25	AFETR predicts to DSS 72, 51, 41
27	27	Nominal transfer orbit (TO) IRV, SOPM, orbital elements
34	30	Tananarive and Carnarvon look angles (nominal TO)
34	37	Moon mapping (nominal TO)
48	41	PO IRV, SOPM, orbital elements
49	42	PO IRV, and injection matrix (I-matrix)
63	62	Preretrofire TO IRV, SOPM, orbital elements
68	63	AFETR predicts to DSS 41
81	72	Preretrofire TO IRV, and I-matrix
77	84	Postretrofire TO IRV, SOPM, orbital elements
89	96	Moon mapping (preretrofire TO)
94	101	Moon mapping (postretrofire TO)
100	104	Postretrofire TO IRV and I-matrix
140	264	Preretrofire TO IRV, SOPM, orbital elements (ORCAL) CRO and DSS 41
144	272	Moon mapping (preretrofire TO) (ORCAL)
145	277	AFETR predicts to DSS 41
155	284	AFETR predicts to DSS 41 (ORCAL)

DSS 41 rise was approximately T+48 min on 99.9 deg flight azimuth.
T = 45:37 actual.

real-time impact predictions for range safety during this period.

In summary, the successive computations performed and transmitted to the DSN FPAC team at the SFOF were:

(1) Two sets of parking orbit and theoretical transfer orbit elements and injection conditions; predicts for DSS 41, 51, and 72 based on one set of these conditions; and one set of conditions mapped to lunar encounter.

(2) Three sets of actual transfer orbit elements and injection conditions; predicts for DSS 41 based on one set of these conditions; two sets of lunar encounter conditions. The third set of elements and injection conditions and the second set of lunar encounter parameters were based on an orbit which contained MSFN data from Carnarvon and DSN data from DSS 41, Woomera.

(3) One set of *Agena* postretrofire orbit elements and injection conditions mapped to lunar encounter.

C. MSFN Performance

1. The VHF telemetry and C-band metric data. Predicted vs actual VHF telemetry and C-band radar beacon tracking coverage is shown in Figs. 33 and 34. All requirements were met and coverage exceeded estimates.

2. Data processing and display. The GSFC Data Operations Branch received all AFETR downrange metric data and generated nominal preflight antenna pointing data and real-time acquisition messages for MSFN land radars. All required computer support was provided.

D. Ground Communications

The NASCOM performance during the near-earth phase met all support requirements satisfactorily. Communications performance to the RIS *General Arnold* and RIS *Coastal Crusader* in the Indian Ocean was closely monitored on launch day because of poor HF propagation encountered during prelaunch tests.

In addition to the AFETR communication facilities, Air Force Western Test Range receiving stations at Hawaii, Kwajalein, Vandenberg AFB, and NASCOM facilities at Tananarive provided additional circuits for relaying RIS *General Arnold* metric teletype data. The HF radio circuit status and a propagation forecast were provided to the Project throughout the countdown.

The metric data circuits to the RTCS were usable; however, three ships downrange were unable to receive the necessary IRV transmitted by the RTCS because of the marginal condition of the RF paths.

A special voice circuit was established between GSFC, JPL, Carnarvon, and DSS 41 and was successfully used to assist DSS 41 with initial spacecraft acquisition.

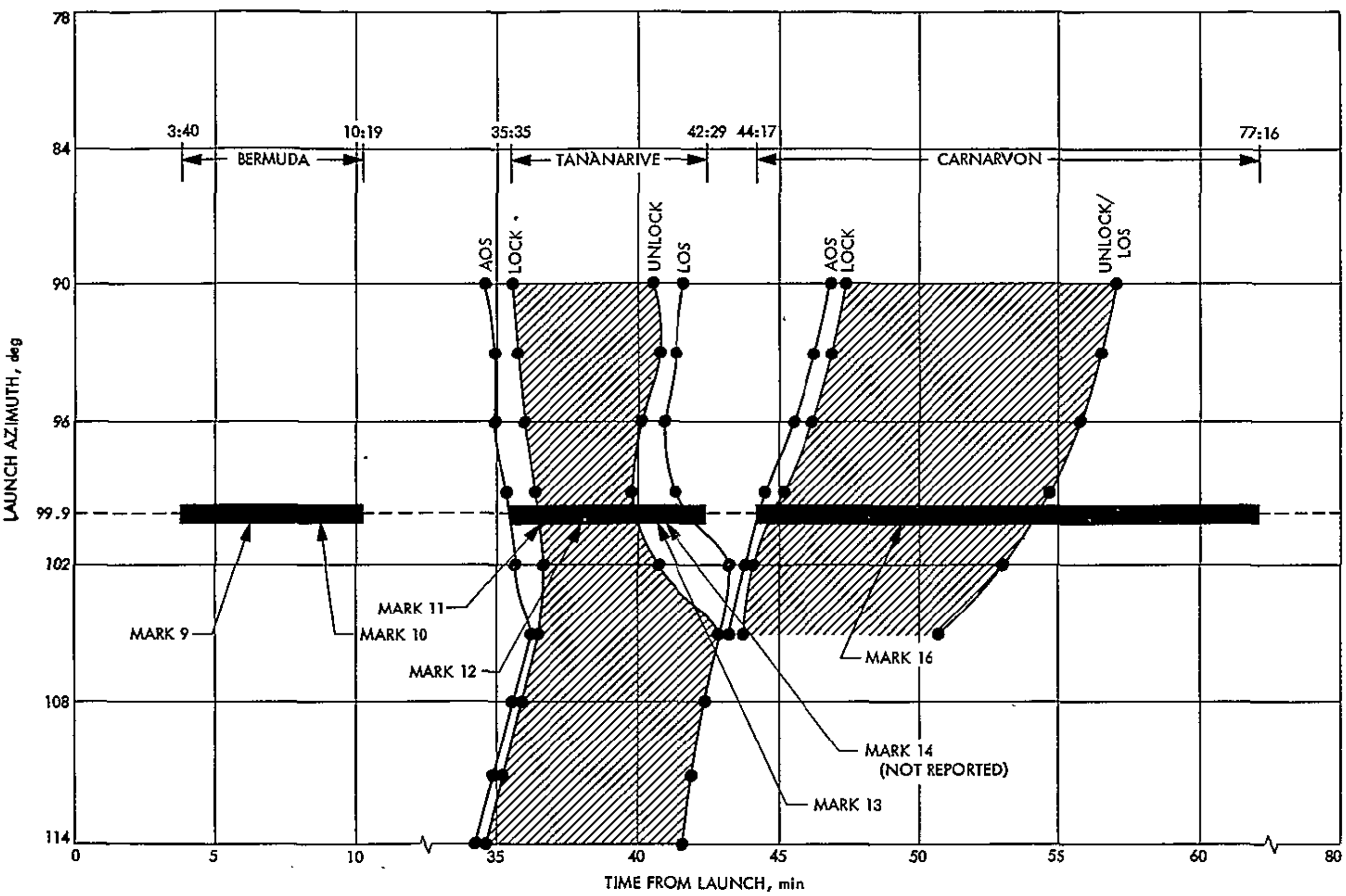

Fig. 33. Mission I MSFN VHF telemetry coverage

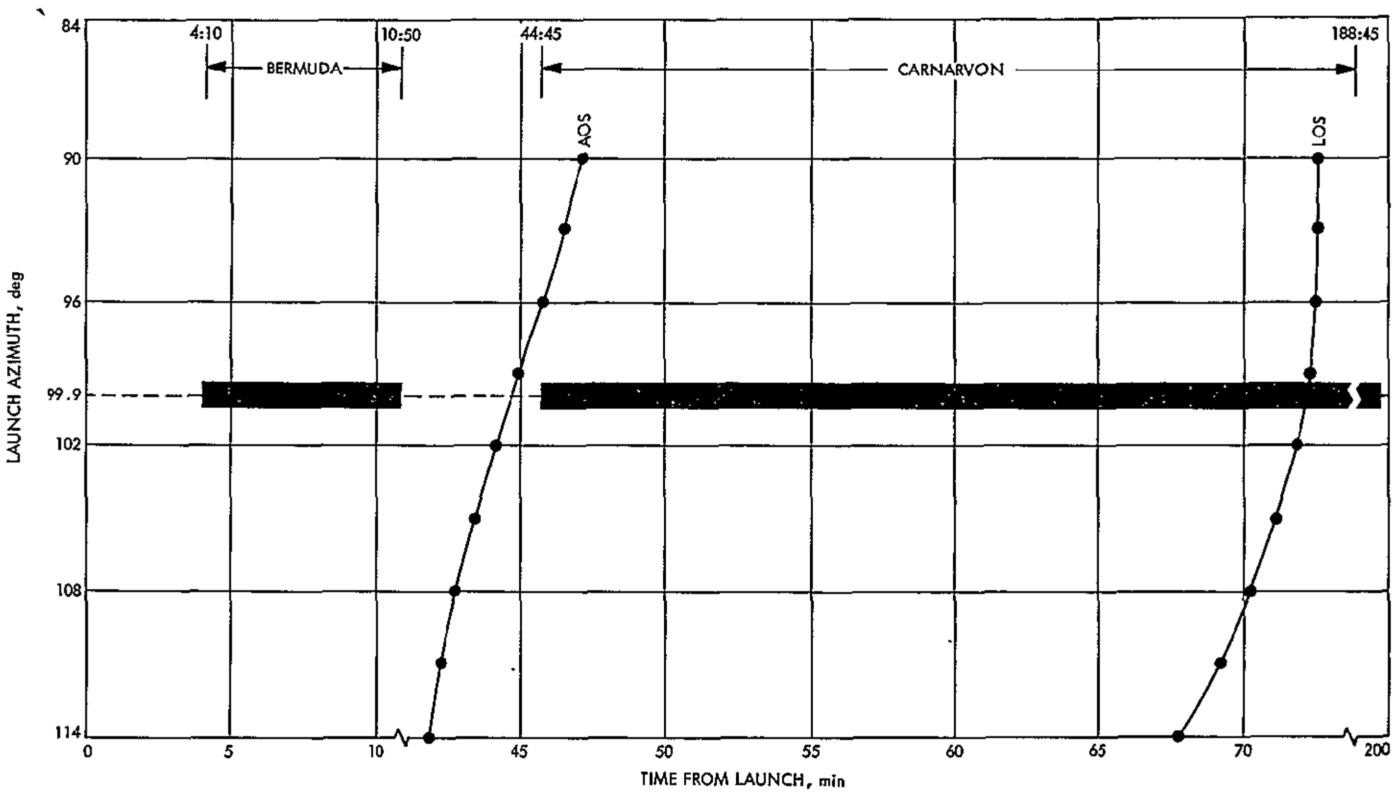

Fig. 34. Mission I MSFN radar metric coverage

E. DSN Processing of Near-Earth Tracking Data

The DSN tracking data requirements placed on the AFETR and MSFN called for the transmission of both raw and computed launch vehicle metric data from the RTCS to the SFOF for use by the DSN FPAC group. A summary of the early orbit determination results computed by the RTCS and the FPAC team is presented in Figs. 35 and 36 and Table 13.

1. *Raw metric data*

a. Performance. All class I raw metric data support requirements were met. The following is a summary of the quantity and quality of raw metric data received by the SFOF DPS.

Bermuda FPS-16 Radar sent four good points of post-parking orbit injection data. Data stopped at a 4° elevation angle at $T+558$ s.

Grand Turk Island TPQ-18 Radar did not provide any raw metric data to the SFOF, although there was at least a 1-min view period after parking orbit injection.

Antigua TPQ-18 Radar transmitted good data for 3 min, 52 s past parking orbit injection, or until $T+756$.

Ascension Island TPQ-18 Radar provided 5 min, 54 s of good parking orbit metric data between $T+1206$ s and $T+1560$ s.

Pretoria FPS-16 Radar provided 5 min, 17 s of parking orbit tracking data and 01:07 min of second *Agena* burn data between $T+1878$ and $T+2262$ s. Pretoria LOS occurred as predicted, approximately 21 s before transfer orbit injection.

RIS *Generald Arnold* data were received between $T+2310$ and $T+2754$ s; 12 points were designated good. About 11 of these points were combined with Carnarvon radar metric data by the DSN FPAC team to determine a backup transfer orbit.

Carnarvon FPQ-16 Radar provided approximately 1 h of metric data starting at $T+2754$ s. Of these, 4 min, 54 s consisted of posttransfer-orbit injection/preretrofire data; the remaining data were taken from the *Agena* stage after the retrofire maneuver. The first Carnarvon tracking data point was at a 12 deg elevation angle. The FPAC team used about 22 points of the Carnarvon preretrofire data and about 11 points of RIS *General Arnold* data to determine the backup transfer orbit.

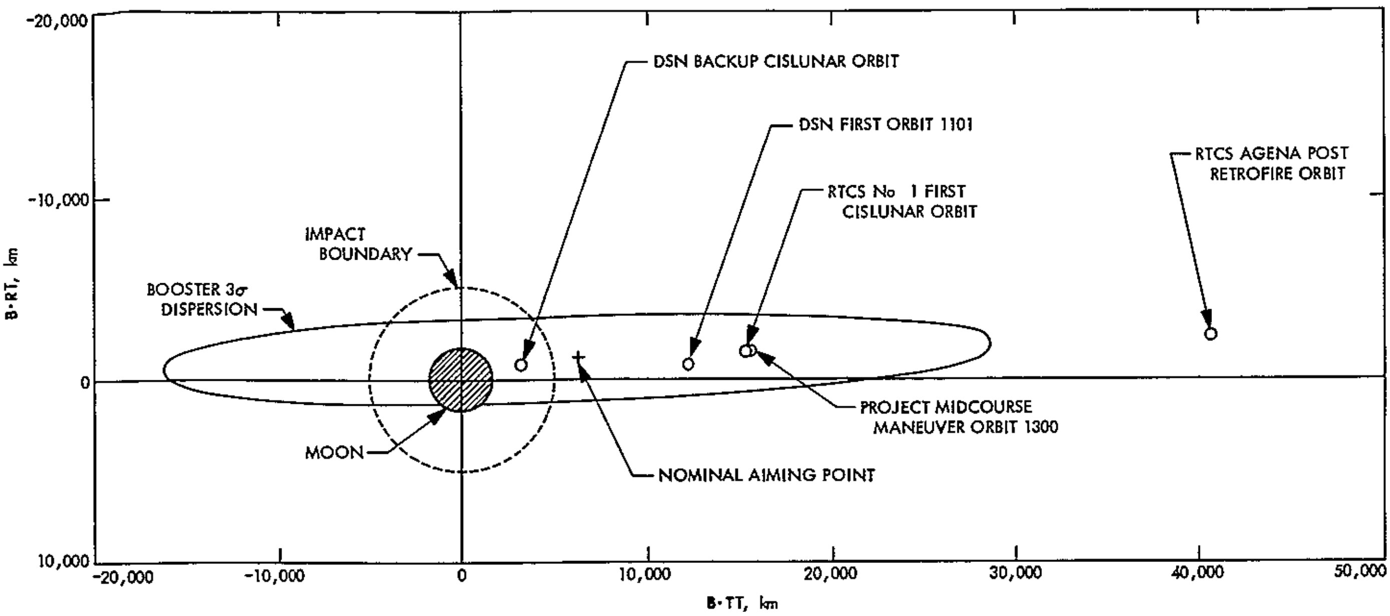

Fig. 35. Mission I early orbit determination B-plane map

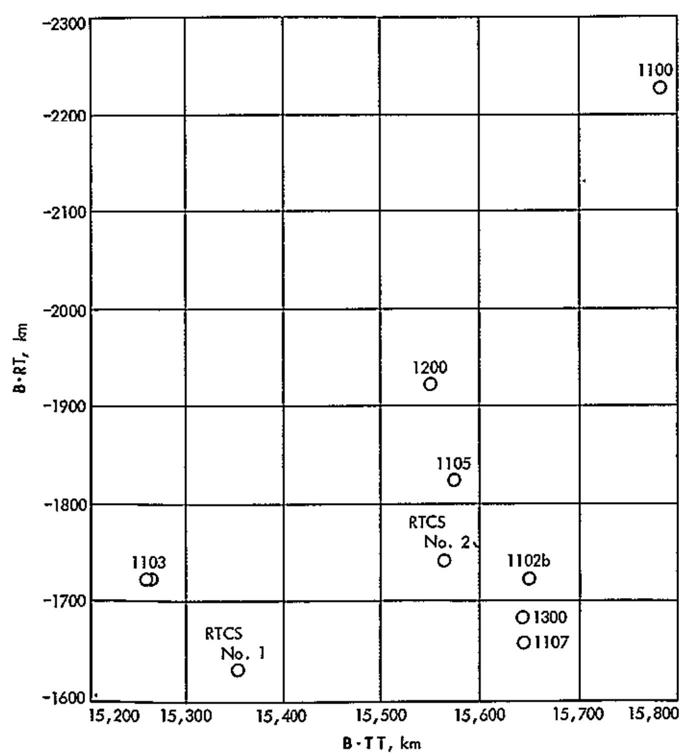

Fig. 36. Mission I early orbit determination results

The DSS 51 provided 20 points of one-way doppler data during the parking orbit. These data were not used, however.

DSS 41 acquired two-way data starting at 20:26:27 or at about $T+1$ h. Angle data prior to two-way lock and about 8 min of two-way doppler data taken at a 10-min sample rate were used for the first orbit based on DSIF tracking data (Orbit 1101).

Approximately 26 min of DSS 41 tracking data were used by the Project FPAC team to compute the second orbit based on DSIF data (Orbit 1100). This computation was performed on the Project computer string.

The DSS 41 continued to provide two-way doppler tracking data; approximately 1 h, 56 min of DSS 41 data and 20 points of Carnarvon FPQ-6 metric radar data were used to compute another orbit (Orbit 1103, Case 1). An alternate orbit (Orbit 1103, Case 2) using only DSS 41 data was computed with essentially the same results as when using both DSS 41 and Carnarvon data.

After more data were accumulated, the orbit was updated using approximately 4 h of DSS 41 data (orbit 1105). This was the last orbit computed by the DSN FPAC team prior to turning over control to the LOP.

b. Problems. Although a sufficient number of support requirements were successfully met, certain elements of the AFETR and MSFN did not provide all of the support expected, viz.:

(1) Bermuda did not track down to their horizon limit.

Table 13. Mission I early orbit determination results

Orbit	B, km	B • TT, km	B • RT, km
Nominal aiming point from targeting specifications		6,320	−1,129
RTCS parking orbit and nominal second Agena performances	14,887	14,817	−1,434
RTCS No. 1 first translunar orbit based on Carnarvon data	15,437	15,351	−1,633
DSN backup translunar orbit based on RIS *General Arnold* and Carnarvon data	3,214	3,103	−836
RTCS Agena postretrofire orbit	43,524	43,461	−2,334
DSN first orbit 1101 based on 8 min of DSS 41 data	14,129	14,095	−978
Project Orbit 1100 based on 26 min of DSS 41 data	15,936	15,780	−2,228
DSN Orbit 1103, case 1 based on Carnarvon and 106 min of DSS 41 data	15,362	15,265	−1,725
DSN Orbit 1103, case 2 based on same 106 min of DSS 41 data only	15,357	15,260	−1,726
RTCS No. 2 orbit based on Carnarvon and DSS 41 data	15,659	15,562	−1,742
DSN Orbit 1105 based on 4 h of DSS 41 data	15,681	15,575	−1,824
Project Orbit 1200 based on 4 h of DSS 41 data	15,671	15,552	−1,924
DSN Orbit 1107 based on 6.5 h of DSS 41 and 2 h of DSS 61 data	15,732	15,645	−1,660
Project midcourse maneuver Orbit 1300 on 6.5 h of DSS 41, 4.75 h of DSS 51, and 5 h of DSS 61 data	15,734	15,643	−1,686
Project Orbit 1102B based on 5 h of DSS 41, 8.5 h of DSS 61, and 2.5 h of DSS 12 data	15,745	15,650	−1,725

(2) Grand Turk tracking data were not received at the SFOF.

(3) RIS *General Arnold* did not provide good metric tracking data.

(4) Carnarvon provided tracking data starting at a 12-deg elevation.

2. *Computed metric data*

a. Performance. The support requirements for the transmission and processing of computed metric data were successfully met. The following is a summary of the actual performance.

The DSN and Project FPAC user program prelaunch checkout cases were successfully completed on schedule in support of the August 10 launch. This was the most successful countdown that the FPAC team had on any simulation or during the August 9 launch attempt.

Spacecraft frequency reports were received from DSS 71 at $T-80$, $T-30$, and $T-6$ min, evaluated by the DSIF SDA group, and frequency parameters were provided to the RTCS by $T-60$ and $T-20$ min.

Radar static points for calibration purposes were received at the SFOF and processed by the DSN FPAC group.

Powered flight trajectory cases (POWL, a computer program) based on expected liftoff times were run by the DSN FPAC group and selected sets of predicts were transmitted to DSS 41, 51, and 72.

The RTCS orbital and predicts computations as listed in Table 12 were received during the near-earth phase.

Predicts for DSS 41, 51, 61, and 12 were generated by the DSIF SDA group from the orbits generated from DSS 41 tracking data.

The JPL Data Coordinator, the mission and flight analysts at Bldg. AO, and the FPAC trajectory engineers and FPAC Director worked as an integrated team to monitor the performance of the near-earth phase of the mission. Since the mission was completely nominal, no nonstandard procedures were initiated.

b. Problems. The DSN FPAC group was not able to efficiently assimilate the vast amounts of data received from the MSFN, AFETR, and the DSIF. This difficulty caused an unreasonable delay in the reporting of mission status to the Project FPAC personnel and to the *Lunar Orbiter* Mission Control Team. No serious problems resulted, but in the event of a nonstandard mission, the FPAC team would have needed much more flexibility in order to support quickly changing mission requirements.

During subsequent *Lunar Orbiter* missions, the efficiency of the DSN FPAC group was increased by:

(1) Elimination of excess personnel.

(2) Elimination of some of the redundant orbit determination and trajectory activities between the RTCS and SFOF and between the DSN and Project parts of the FPAC team.

(3) Elimination of the requirement to run POWL just prior to and after launch. A plan was developed to permit running the predicts program (PRDL) without previously running POWL.

IV. Deep-Space Operations and Performance Summary

A. DSN Performance

1. General. With minor exceptions, all DSN commitments to the Project were met. Approximately 2000 h of computer support and 1500 h of DSS support were provided during the mission. Both ranging and station time correlation experiments using the ranging transponder aboard the spacecraft were successfully conducted. The time correlation experiment measurements were corroborated by a Project-sponsored Naval Observatory atomic clock which was sent to DSS 12, 41, and 61.

The performance of the Project-sponsored DSN FR 900 tape recorder provided for the LOP was satisfactory.

2. Scheduling. Out of approximately 11,000 computer h available to all space flight projects during FY 1967, the *Lunar Orbiter* Project requested 8000 h. This level of use was substantiated by the experience gained during Mission I. Approximately 12,000 tracking h were available at DSS 12, 41, and 61 during FY 1967. The *Lunar Orbiter* requirement for 8000 h placed heavy emphasis on scheduling which was to remain a significant problem during the life of the Project.

The scheduling of *Lunar Orbiter*, *Pioneer*, and *Surveyor* Project launches into August and September required numerous scheduling negotiation meetings between the DSN and the projects involved. During this period all projects were required to modify data processing and station coverage commitments; there were no serious compromises, however.

3. Operations. A Supervisor of Network Operations (SNOMAN) position was established by the DSN Manager for *Lunar Orbiter* to provide a single point of contact between the DSN and the Project during operations. The position was manned around the clock by the DSN PE for *Lunar Orbiter* and his staff. The purpose of the SNOMAN position was primarily to ensure that DSN–Project commitments were met and properly channeled between the DSN and Project operations groups. At times during the mission, the SNOMAN position tended to get too involved in operations while during other prolonged periods the SNOMAN had nothing to do.

4. Configuration control

a. Control procedure. The DSN-Project Interface Control Document was intended to serve as a configuration control document for Mission I but late inputs for necessary revisions prevented its use for this purpose. A large contributing factor was a flood of last-minute inputs from the Project requesting changes in the SFOF. An informal configuration control was maintained by requiring the signatures of both the SFOF Director and the DSN PE on all change requests. This system apparently worked very well in processing 11 change requests between August 1 and September 16, and 57 premission change requests during the months of June and July.

b. Data Processing System. For periods of up to one wk, all three SFOF computer strings were used simultaneously by the Project, two in Mode II (real-, near-real-time processing) and one in Mode IV (non-real-time processing). The basic DSN commitment to the Project was for one reliable Mode II string with a second Mode II string to be made available only as a backup to enhance reliability. The Project, however, employed the second Mode II string to increase data processing speed. Immediately following Mission I, the Project began modifications to eliminate the need for separate processing of orbit determination and spacecraft analysis programs in a dual Mode II configuration. Mode IV operation was restricted to the second (backup) string unless the third string was available.

5. Failure Reporting System. The DSN Discrepancy Reporting System (DRS) classifies failures and problems as either critical, urgent, or routine. Critical discrepancies are those which would result in a launch hold or would affect mission objectives. Urgent discrepancies are those which would result in a loss of data or command capability. All others are classified as routine. Appendix B provides a breakdown and comparison of discrepancy reports generated during Mission I and subsequent missions.

B. DSIF Performance

1. *Flight summary*

a. Launch and initial acquisition phase. Liftoff occurred at 19:26:00 GMT, August 10, 1966. The DSS 71 tracked the spacecraft manually in one-way lock for 3 min and 20 s before the spacecraft passed out of range.

DSS 51 acquired the spacecraft at 19:58:47 and lost lock at 20:02:36 as predicted. Due to the high spacecraft angular rates the station had difficulty in maintaining lock and was unable to record any telemetry data.

At 20:13:38, DSS 41 acquired the spacecraft in one-way lock with Receiver 2 on the S-band acquisition aid antenna (SAA). Receiver 1 was locked up at 20:13:33. The station was in autotrack on the SAA at 20:14:37 and was in autotrack on the main beam of the antenna at 20:14:45.

The transmitter was turned on at 20:16:30 and Receiver 2 was in two-way lock at 20:22:42. Receiver 1 was in two-way lock at 20:23:07 but on a sideband. At 20:23:58, Receiver 1 was taken out of lock and then locked on the main carrier at 20:24:50. Autotrack in two-way mode was achieved at 20:24:55. After achieving good two-way lock, the DSS 41 exciter frequency (X_A) was found to be 50 Hz off predicts. This deviation was later found to have been the result of a 1° increase in spacecraft transponder temperature. The predicts had been based on a Project forecast of an 11.5° temperature increase.

b. Transit and lunar phase. Activities and performance during the transit phase were nominal. The DSN Ranging Subsystem was used for the first time after the midcourse maneuver and timing synchronizations were performed between the stations.

After injection into lunar orbit, the computer-driven antenna pointing system (APS) was initiated during three-way lock periods to prove the adequacy of this system to point the antenna during photo readout periods when there was no carrier present. The APS proved reasonably successful and stations were instructed to use it instead of autotrack when in two-way lock. Minor problems were experienced during photo readout; some photo data were lost in real time but were recovered during the final readout. During critical periods, the antenna was pointed manually.

c. Signal levels. During the lunar phase, the downlink-received power decreased approximately 6 dB from the expected nominal over a period of 12 to 18 h. This problem was later traced to a spacecraft omniantenna malfunction. In addition, the spacecraft automatic gain control (AGC) level showed a rising input level with no changes in ground transmitter power and with proper ground antenna pointing.

The signal levels received at the prime stations were between 4 and 5 dB above predicted nominal values, except for those periods when there were unexplained signal level changes as noted above. Signal level recordings from two stations varied between 0 and 4 dB during times when the spacecraft was in common view. These two signal level changes were traced to spacecraft malfunctions.

Throughout the mission, all stations remained within performance specifications.

d. Station anomalies. Significant anomalies, their causes, and effects on the mission are listed in Table 14. All prime stations performed normally and were able to work around such anomalies as did occur.

2. *The DSIF operations.* Overall DSIF operations performance was very satisfactory with respect to meeting the commitment. The incidence of individual operational errors was very low. The DSIF tracked for a total of 1003.53 h, of which 816 h were committed, thus providing tracking coverage 20% above the commitment.

In general, all operational procedures worked well; in some areas, however, operational performance could have been smoother and procedures were modified to improve performance during subsequent missions. The specific areas of improvement were:

(1) Providing the Project with status information on a regular basis.

(2) Spacecraft antenna mapping.

(3) Acquisition and station transfer.

(4) Tracking data sample rate changes.

A summary of the total coverage provided by the DSIF during Mission I is provided in Table 15.

3. *Telemetry monitoring.* Telemetry data monitoring was limited to determining that a data stream was passing a given monitor point in the DSN system and verifying that all DSN equipment were operating within tolerances.

Table 14. Mission I summary of DSIF anomalies

DSS	Day, 1966	Time, h:min	Anomaly	Probable cause	Remedy	Effect on mission	Comment
41	222	20:43	Command no. 1 not sent on time	Command modulation not turned on	Retransmit command	None	DSS advised of correct operational procedure
61	223	07:30	Transmitter turned on at 10 kW instead of 1.6 kW	Tracking Instruction Manual power profile not followed	Reduced power	None	DSS advised of correct operational procedure
61	223	07:30	DSS 61 had difficulty in handover from DSS 41	Predicted acquisition frequency wrong due to incorrect rise in spacecraft temperatures provided by Project	Exciter tuned until spacecraft acquired	None	Project to supply transponder temperatures to Systems Data Analyst and Operations Engineer.
61	223	08:50	TCP computer beta inoperative	Bad FF Card No. FR-52 in location J-18A	Switched to computer alpha	None	Common failure
12	223	18:43	Paramp in oscillation	Unknown	DSS was on maser at time paramp was shut down	None	Random failure
61	226	10:59	Transmitter shut down	Tripout of klystron undercurrent interlock delay	Reset klystron voltage. Turned transmitter back on	None	Common failure
61	227	20:01	Receiver 1 jumped to sideband	Unknown	Unlocked receiver 1 from sideband. RF locked on carrier	None	Receiver 2 stayed locked up on carrier
12	241	08:30	Maser warmed up	Unknown	Switch to paramp	None	Common failure
61	252	03:15	Transmitter shut down	Flexible coupler pulled loose dumping heat-exchanger water	Coupler replaced within 1 h	None	Random failure

Table 15. Total DSIF coverage summary for Mission I photographic and extended mission phases

DSS	Two-way tracking, h	Three-way tracking, h	Total tracking, h	Ranging, h	Time correlation, h
12	342.50	50.61	393.11	22.18	1.03
41	359.52	66.25	425.78	67.67	1.87
51	4.52	11.04	15.57	0.00	0.00
61	400.63	55.12	455.76	77.31	0.23
71	0.00	0.05	0.05	0.00	0.00
Totals	1107.17	183.07	1290.27	167.16	3.13

All DSIF stations remained within telemetry processing performance specifications. A fault in the APS at DSS 12 resulted in the loss of approximately 1 min of both telemetry and tracking data during the eighth pass. All data received at the stations during the photographic mission were recorded and made available to the Project. This DSIF recording capability was utilized to recover lost data and all but 35 min of data were recovered during the course of the mission. Approximately 2 h of data were lost due to SFOF data processing problems. The total represented a received data loss of less than 0.25%.

4. *Tracking data monitoring*

a. Performance summary. DSIF SDA group provided around-the-clock support from launch until the end of the photographic phase of the mission. This effort included rough-cut tracking data monitoring and quality assessment for the FPAC Orbit Determination Group, frequency inputs to the Orbit Determination Program (ODP), acquisition predicts for the DSIF, and consultations with DSIF operations engineering personnel on the solutions to problems.

The monitor function was performed essentially by the Goldstone Tracking Data Monitor (TDM) program using the SDS 930 Computer which displays its output in teletype format in the form of angle and doppler pseudoresiduals relative to an onsite trajectory program, or to SFOF predicts, detrended doppler pseudoresiduals, and doppler standard deviation. In general, this program functioned very well within its limitations. It was of particular value in confirming the accuracy of propulsion maneuvers.

The DSIF predicts were generated in a timely manner with a small number of exceptions. One delay occurred approximately 4 h after launch when the ODP was iterating on early DSIF data and a decision was made to wait briefly for a new state vector rather than run with an old one. A similar occurrence took place during photo readout, predicts for the next orbit being sent during occultation. These delays did not affect tracking performance.

Tracking data were generally well handled at the DSIF sites and within the GCF with very little data lost to the users because of garbling in transmission; data were lost fairly often within the SFOF because of computer I/O problems.

The DSIF transmitter frequencies, data type, and data monitor logs were kept in very nearly real time to the end of the mission photographic phase. Occasional frequency input errors delayed the FPAC tracking data quality determination effort; in most cases these were found to be keypunch errors.

b. Tracking data validation. The TDM program enabled the midcourse and injection maneuver doppler variations to be plot-displayed within 1.5 min or less of real time.

The TDM used JPL predicts exclusively as its residual reference in lunar orbit. Using the full capabilities of this program, however, the TDM residuals nevertheless showed large periodic excursions (±100–500 Hz) which were synchronized with the spacecraft orbital motion. These data were informative in estimating the validity of orbit determination (OD) conditions and harmonic solutions, but the large rates of change in the residuals rendered the TDM noise estimates essentially meaningless. However, whenever the receiver was inadvertently locked on a sideband, the condition was readily discernible in the TDM as a ±10 kHz doppler change.

The TDM was used to monitor and plot the first and second orbit transfer maneuvers. These were run with valid results on a deviation-from-no-maneuver basis. A timing anomaly at DSS 41 was not detected by the TDM until after the fact, due to the use of an early post-second transfer predict set with an inherently low confidence.

In general, the TDM doppler residuals in lunar orbit were consistent in pattern from one orbit to another within a predict set but showed little consistency between sets as run on successive OD solutions. As a rule, the oscillations in the ODP residuals at periselenic passage were discernible in the TDM plots.

c. Problems

Predict Program (PRDL). Errors of up to 4 min occurred in the coding for occultation time computation. The transponder best-lock and auxiliary oscillator frequencies were usually out of date because of the wide variations in spacecraft temperature. Some means for rapidly and reliably evaluating frequencies became highly desirable since information obtained from SPAC during Mission I was usually ambiguous even as to the sign of correction terms.

The PRDL program required very long lunar orbit running times and was often in competition with other FPAC programs, particularly ODP, on which PRDL depends for initial conditions. This conflict became quite serious during critical mission sequences.

Tracking data handling. In the early phases of the mission, the TDM function was adversely affected by the transmission of tracking data in batches. An agreement was reached to send data continuously for the remainder of the mission and, it was hoped, obtain a separate tracking data line for the remaining missions.

The DSS overlap scheduling during lunar orbit was inadequate. The data derived from DSS overlap were classified as important in that they improved both orbit determination and prediction accuracy.

A software incompatibility existed in the TDP–ODG between octal and decimal data in the Tracking Data Handling (TDH) Subsystem ranging field. It was desirable to record transmitter voltage-controlled oscillator (VCO) frequency in this field for operational reliability at times when ranging was not operating. A conflict arose during ranging, however, if all participating DSS were not in ranging format simultaneously. Data were either rejected or required laborious processing.

5. *Ranging and time synchronization.* The first acquisition of range by the Mark I Ranging System on an actual spacecraft was accomplished at 13:12:02 GMT on August 12, 1966. In addition, an attempt was made to measure the difference between the station master clocks by using the ranging system at each of the DSS sites committed to the *Lunar Orbiter* Mission. The clock synchronization experiment was performed to support a Project request for information on the deviation of DSS master clocks between sites with an uncertainty of 50 μs or less. This measurement was not possible using the standard WWV synchronization techniques (Table 16).

Table 16. Time synchronization experiment results

Day	Time, GMT	DSS	Clock with respect to DSS 12, μs
228	18:00	61	+7617.5
229	01:00	41	−2091.9
257	06:30	61	+7075.0[a]
257	22:30	41	−1840.0[a]

[a]Operator error at DSS 61 prevented direct comparison with DSS 12. Error obtained via DSS 41/61 synchronization.

a. Ranging results. Data were obtained from DSS 12 during the translunar phase and from DSS 12, 41, and 61 during the orbital phase. Two correlations were made on the data, one against the predicted range from the orbit determination program based on integrated doppler, and a second for noise on the ranging data. The ranging system had an expected accuracy of 15 m or better. The ODP range prediction had an uncertainty of several hundred meters due, in most part, to ephemeris errors. The residuals obtained by differencing the ranging data with the predicted range were less than the uncertainty in the predicted range. Over 1000 independent acquisitions were accomplished.

Data noise was measured by a combination of measuring the noise on the orbit determination residuals and comparing the counted doppler between range points to the difference in range. Since the orbit program has a truncation error of 4 m at this distance, its error was on the order of 3 m during the translunar ranging. Actual data comparison gave an error on the order of 3 m. During the first week of ranging with DSS 12, 61, and 41, a noise level of 5 m was indicated. When ranging was continued after the photo readout, however, the noise level had increased to approximately 12 and 30 m peak-to-peak.

A request was made to obtain ranging data as soon after launch as possible (e.g., during the first pass over DSS 41, 61, and 12) to facilitate rapid early-orbit determination and provide an opportunity to evaluate ranging performance while the orbit determination range uncertainty was still low (25–50 m).

b. Station time synchronization results. Time synchronization was actually a measurement of the time difference between the DSS master clocks by measuring the difference between the 1 pulse/s signal generated by the DSS clock and a commonly received sync pulse for the range code. Test and implementation were relatively simple; only one additional cable was required. Although problems occurred due to operator error, the procedure was not difficult and problems were expected to diminish as the operators became more familiar with the system. Because of several failures of the DSS clocks during the mission, it was strongly recommended that measurements be performed at least twice a week during the entire mission, if an accuracy of 50 μs or better was desired. Although more data were taken for evaluation purposes during the initial tests, it appeared that 10 points of data on 30-s centers were sufficient. Initial tests showed it was unlikely that more than 1 point out of the 10 would contain erroneous data and that the remaining points would all fall within a band of ±1 μs of the mean.

C. GCF/NASCOM Performance

1. *Performance summary.* Other than minor circuit outages normally experienced and expected during mission operations, the only significant anomaly occurred after launch when all three teletype and high-speed data circuits between the SFOF and DSS 61 were inoperative for 20 min. The outage was attributed to the commercial carrier at the Madrid facilities. The problem was of a nonrecurring nature and required no action to prevent recurrence during future missions.

2. *Scheduling.* Difficulty was experienced with the scheduling of communications resources, primarily due to

the scheduling interrelationships with other projects. Realignment of schedules and real-time modification of previously scheduled activities became the rule rather than the exception during the mission.

3. Staffing and training. Additional operations personnel required for the mission were obtained through the use of overtime. Personnel training, although always a problem, was not of a serious nature during Mission I.

D. SFOF Performance

1. Data Processing System. Data Processing System performance was exceptionally reliable for its size and complexity. There are 14 spacecraft analysis programs, 26 FPAC programs, and 2 miscellaneous programs. There were 4 SFOF power failures/outages which combined to produce a total data loss of only 4 min. During the early portion of the mission, a communications inconsistency between the IBM 7044 and 7094 computers caused repeated system failures. Total time loss was approximately 2 h. There were no software system failures; errors that were encountered were either accommodated or circumvented.

In general, hardware performance was outstanding. Intermittent problems with the 1301 disk files consisted primarily of format and parity errors; these occurred during noncritical times and did not seriously affect the mission. Investigation revealed that 90% of the problems were due to Project software.

2. The SFOF operations. Overall operational performance was good. Problems encountered were due to dual mission support, inadequate Project familiarization time after the conclusion of the *Surveyor I* mission, and limited training time. The majority of the problems were procedural and were quickly resolved.

3. Staffing and training

a. Procedures. Familiarization of Project personnel with current DSN operations procedures would have eliminated most problems. Project and DSN DPS personnel lacked familiarity with each other's internal procedures.

b. Software coordinator (DACON) procedures. A notable shortcoming during the preparation of Mission I was the lack of DACON (data controller) procedures. An incomplete set of procedures was issued some weeks in advance of launch, but were of limited value. Classroom training material for the Project DACON was subsequently transcribed on paper and, the night before scheduled launch, handwritten copies were issued to the necessary personnel. After inevitable publication delays, the final document was distributed on the last day of the photographic mission.

The DACON frequently complained that personnel manning the SNOMAN position were unacquainted with the computers and the software. The complaints diminished as the mission proceeded, but a data processing class was offered to acquaint SNOMAN with the data processing system before the next mission.

E. DSN FPAC Performance

1. Performance summary. At the start of the DSN FPAC team countdown for the first launch attempt on August 9, there were operating problems with both X and Y SFOF computer strings. An attempt was made to operate from the Surveyor FPAC area using the W computer string but this proved to be impractical. As a result, only a limited number of FPAC program prelaunch checkout cases were run prior to the terminal countdown phase at $T-70$ min. Spacecraft transponder frequency reports were received and powered flight trajectory cases were run successfully before the launch was scrubbed.

On August 10, the FPAC team ran through all of the required prelaunch FPAC program checkout cases and many of the nonmandatory cases. Transponder frequency reports were received from DSS 71 on schedule, and frequency parameters were supplied to the RTCS and DSIF for the generation of predicts. All of the powered flight trajectory (POWL) cases based on expected liftoff times were run as required. The actual liftoff time POWL cases were canceled since the expected liftoff time POWL cases provided sufficient data. The Orbit Determination (OD) group used MSFN and AFETR data to back up the RTCS parking orbit and transfer orbit determination. The required orbital elements and injection conditions, predicts for DSS 72, 51, and 41, mark event times and lunar encounter data were received from AFETR and evaluated by the FPAC team. The DSN OD group received and processed DSS 41 tracking data and ran four separate orbit determinations, including one by Project personnel, before control of the FPAC team was relinquished to the Project at $L+6$ h. Predicts and trajectories were run based on these orbits and predicts were sent to the appropriate DSS.

The raw tracking data supplied by the MSFN and AFETR, the computations performed by the RTCS, and the performance of the SFOF DPS during Mission I were very reliable. These factors plus nominal launch vehicle and spacecraft performance and the early acquisition by DSS 41 allowed the FPAC team to operate very smoothly.

2. *DSN tracking data quality determination (TDQD)*

a. Launch phase OD and TDQD performance. During the first 6 h after launch, the orbit determination process was a DSN responsibility, but both DSN and Project OD personnel collaborated in generating the first orbit determination. The orbits were generated on schedule and showed a nominal injection which was subsequently verified by later Project OD computations. All data used for the midcourse maneuver OD computation were evaluated by the TDQD program and assessed as good. A low amplitude (0.03 Hz) 30-min periodic error was found in the DSS 61 three-way doppler data and these data were not used.

b. Midcourse to injection phase. During the post-midcourse phase, the data were plagued with perturbations resulting from spacecraft pitch and yaw maneuvers which were performed every few hours to regulate spacecraft temperatures and to investigate a Canopus sensor anomaly. The maneuvers added small accelerations to the spacecraft, all in approximately the same direction, and were of concern to the Orbit Determination group. Their effect on the prediction of position at lunar injection was estimated to be less than 10 km, but a better analysis should be made if maneuvering throughout the cislunar phase is to continue on future missions. With the exception of approximately 3 h of DSS 61 data, all doppler data residuals obtained during the period from midcourse to injection were found to be good and met the commitment specification of 0.2 Hz.

c. Lunar orbit phase. Excellent tracking data were obtained after injection and during the initial lunar orbit. Tracking data analysis showed consistency between all three stations. When systematic errors appeared, they occurred at all tracking stations at the same time in the orbit, i.e., near pericenter passage; it was concluded that these errors were caused by unknown lunar gravitational effects and not by any tracking station phenomena. The errors were seen more prominently during the final picture-taking orbits when the spacecraft altitude was much lower. An extensive effort was made by the TDQD group to resolve these effects which caused doppler data predictions to be off by ±100 to 500 Hz within a 2-day period. An RF multipath effect, temperature variations, and the possibility of a loose omniantenna were considered as possible causes and then ruled out one by one as more data accumulated. Other possible sources: (1) a higher order harmonic not considered in the potential model, or (2) an error in the higher derivatives of range used in the ODP to calculate doppler. The impaired doppler predicts capability was a direct result of the large excursions in doppler rates which also made a valid TDQD result next to impossible.

3. *Problems, comments, and recommendations*

a. Scheduling. During both prelaunch checkout and the mission itself, computer scheduling authority and the establishment of priorities between the Project and DSN were unclear.

b. Hardware. Backup tracking data on IBM cards inputted through the IBM 047 were used several times due to DPS failures which prevented data storage in the IBM 1301 disk file. In particular, disk tracking data were not available during one of the transfer maneuvers into final orbit and cards were used to establish the first orbit.

c. Data accuracies and coverage. With the exception of a few isolated cases, the quality of the tracking data was very good. Data accuracy was below 0.01 Hz (standard deviation) for a 1-min sample taken at any time during the mission; i.e., a factor of 20 better than the NSP commitment.

Better planning of OD tracking data needs, spacecraft telemetry, photo readout times, and station tracking periods was emphasized.

Part III. *Lunar Orbiter II*

I. Introduction

A. Mission II Objectives

The objectives for Mission II were first, "To obtain, from lunar orbit, detailed photographic information of various lunar areas, to assess their suitability as landing sites for *Apollo* and *Surveyor* spacecraft..." Also included in the survey was the impact area of *Ranger VIII*. The photographic sites were located along a northern latitude band within the *Apollo* zone; Mission I sites were along a southern latitude band. The secondary aims were (1) to provide precision trajectory data in order to gain more precise information about lunar gravitational harmonics, and (2) to obtain micrometeoroid flux and radiation dose measurements of the lunar environment, primarily for spacecraft performance analysis.

B. Mission II Summary

The Mission II spacecraft was launched from Complex 13, Cape Kennedy, at 23:21:00 GMT, November 6, 1966, on a flight azimuth of 92.9 deg. The liftoff was successfully accomplished at the beginning of the launch window of November 6 to 11. Preliminary analysis of AFETR tracking and telemetry data indicated satisfactory performance by the first- and second-stage vehicles. The *Agena*–spacecraft combination was placed in a 100-nmi-altitude parking orbit and then injected into a cislunar trajectory 20 min after launch. The spacecraft then separated from the *Agena*, automatically completed its deployment sequences, and acquired the sun. A single midcourse maneuver was successfully performed 44 h after launch. After 92.5 h of cislunar flight, the spacecraft was injected into an initial high lunar orbit with a periselenium of 196 km and tracked for several days to obtain data for a more accurate analysis of the lunar gravitational effect. After 33 orbits, the spacecraft was transferred to the photographic orbit with a periselenium of 49.7 km. Lunar photography began on November 18, 11 days and 16 h after launch, and ended on November 26. Readout and examination of the photographs continued routinely for the next 11 days. On December 7, the traveling wave tube amplifier of the spacecraft failed to turn on; repeated attempts to overcome the failure were unsuccessful and the photographic mission was terminated. Tracking by the DSN was terminated on October 11, 1967 when the orbit was modified so that the spacecraft would impact the moon.

All requirements placed on the TDS for support of Mission II were met and, in many areas, exceeded.

II. Preflight Readiness

A. General

The preflight readiness of the TDS was established by means of DSN Compatibility, Verification, and Readiness Tests, a DSN Readiness Review, and a Near-Earth Readiness Review. The reviews were held approximately 2 wk before launch and were organized to determine the capability of each TDS element for supporting the mission, to specifically identify and discuss any existing or expected problems, and to establish a schedule for their resolution. The results were then submitted by the TDS Manager to an overall Flight Readiness Review which was conducted by the *Lunar Orbiter* Project at Cape Kennedy.

B. Preflight Tests

Preflight testing for Mission II proceeded according to the test plan and philosophy described in Part I, Section VI.

1. Spacecraft–DSIF Compatibility Tests. Spacecraft–DSIF Verification Tests were conducted at DSS 71, Cape Kennedy, to establish the compatibility of the spacecraft with the DSIF configuration. Tests uncovered a ranging code phase reversal in the transponder that caused the ranging system to read range numbers improperly. Analysis of this problem indicated that the anomaly could be worked around by inserting minor changes in the FPAC orbit determination programs. This solution accommodated Project personnel, who were reluctant to alter a flight-approved spacecraft. The DSIF support was committed only on a best efforts basis, however, because of the nonstandard transponder.

2. Software Integration and Verification Tests. Tests were conducted between October 14 and 18, 1966 to verify software changes to the command program, to increase the 7094 processing speed, and to verify several small changes made to FPAC and SPAC programs for simplifying operations.

3. Near-Earth Phase Tests. Near-Earth Phase Tests were performed in conjunction with the TDS Operational Readiness Tests (ORTs). Changes in the AFETR coverage plan to accommodate wider launch corridors were requested by the Project approximately two weeks before launch. The AFETR advised that it was too late to revise the plan and that support outside the original corridors would be on a best efforts basis.

The first ORT, held on October 28, simulated a 78-deg flight azimuth. Numerous problems were encountered, mainly with the RTCS 3100 and 3600 Computers and the data transmission lines. Other faults resulted from deficiencies in computer programs used for the simulation. A second such test was conducted on November 2 to simulate the more southerly launch azimuths.

4. TDS Operational Readiness Tests. Combined tests of the AFETR, MSFN, NASCOM, and DSN systems were conducted satisfactorily on October 28 and November 2. End-to-end-data-flow configurations were tested with simulation data provided by the Project.

C. Near-Earth Readiness Review

The Near-Earth Readiness Review was held at Patrick AFB, Florida, on October 12. The items discussed and requiring some kind of resolution were routine ones clarifying operational procedures, adding communications circuits, and scheduling tests. The more significant problems were as follows:

(1) Integration tests were needed, particularly to exercise Grand Canary Island station and the RIS *Twin Falls,* since neither of these stations had yet participated in a *Lunar Orbiter* ORT.

(2) The AFETR coverage plan was late owing to differences between the conic projections supplied by The Boeing Company and the final firing tables.

(3) Optimum ship positions were not obtainable because of conflicts in schedule with *Titan III* and *Gemini* launches; telemetry aircraft were used to fill a gap in telemetry coverage near the African coast.

(4) Some equipment aboard the RIS *Twin Falls* and the RIS *Sword Knot* was not functioning properly.

D. DSN Readiness Review

The DSN Readiness Review for Mission II was held at JPL on October 14, in preparation for the Flight Readiness Review to be held at Cape Kennedy on October 19. In general, DSN preparations and support for Mission II were similar to Mission I. Again, the usual kinds of equipment and operational problems arose involving the Project and the DSN, but none were considered critical. The more important items discussed were as follows:

(1) Ranging and time synchronization performance limitations resulting from the spacecraft transponder code reversal (see paragraph B-1).

(2) FR 900 tape recorder compatibility tests and a Project request for computer company technicians at the overseas stations for Mission II.

(3) Limitation to a best efforts basis on the use of the outbound high-speed data lines for simulation, from SFOF to overseas sites.

(4) Two-way acquisition and mission support by DSS 51 on a best efforts basis for the first 12 h of the mission.

E. Flight Readiness Review

A Flight Readiness Review of all Project and TDS elements was held at Cape Kennedy on October 19, 1966. The TDS summarized the readiness to support Mission II as follows:

(1) The established launch schedules for *Gemini* prevented the MSFN and the AFETR from supporting a *Lunar Orbiter* launch on November 9, 10, and 11. In order to prepare for a *Lunar Orbiter* launch on any one of these days, the TDS required a minimum notice of 24 h for a *Gemini* postponement.

(2) Conflicts between ORTs and other AFETR launch support activities appeared to be solved by means of work-around scheduling.

(3) A definitive schedule for near-earth support would not be available until November 1 or 2, owing to difficulties arising from the use of conic projections in lieu of actual firing tables; these data had been submitted too late to support initial calculations for locating ships and defining coverage for various launch azimuths. Launch corridor coverage would contain some gaps, but satisfactory launch windows were indicated for each day of the opportunity.

F. Flight Readiness Review Follow-Up

A follow-up was conducted by telephone on November 2 and 3, 1966 to determine the state of open or incomplete action items noted at the October 19 Flight Readiness Review. All open items were successfully closed; these included

(1) Completion of metric and telemetry data coverage estimates.

(2) Repair of S-band equipment on board the RIS *Sword Knot.*

(3) Tests on the compatibility of SFOF X and Y computer strings.

(4) Minor changes to computer programs and operating procedures for rendering the DSIF compatible with the nonstandard spacecraft transponder.

(5) Tests for FR 900 tape recorder compatibility.

(6) Checkout of Project ground reconstruction equipment installed at the SFOF for Mission II.

(7) Reformatting of Grand Canary station data for transmission in real time.

(8) Optimum positioning of Range Instrumentation Ships.

III. Near-Earth Operations and Performance Summary

A. Countdown and Flight Analysis Summary

The countdown included two planned, built-in holds consisting of a 50-min hold at $T-60$ and a 10-min hold at $T-7$ min. The launch window for November 6 and 7, 1966 was 123 min long, extending from 23:21 GMT to 02:14. The launch countdown started at 15:11 on November 6 and, with few exceptions, the TDS was continually in a *go* state. Problems that did occur were resolved without additional hold time. Early in the count, a communications patching problem at Cape Kennedy Tel-2 delayed the transmission of *Agena* Channel F telemetry to DSS 71 for 30 min. At $T-235$ min the Antigua TPQ-18 radar was declared in the red because of a computer failure, but was declared operational again at $T-160$. At $T-62$ the Bermuda radar was placed in the red for 14 min because of a timing problem. The count was resumed after the 50-min hold at $T-60$ and proceeded normally to liftoff at 23:21:00.195 GMT. The near-earth support station configuration for Mission II is shown in Fig. 37.

Nominal near-earth mark event times versus actual times are shown in Table 17. In all cases, the difference between actual and nominal times was within tolerance. The marks were reported in real time by the AFETR and the MSFN, and were followed later with a confirming report of the precise times of occurrence. Table 18 lists the reporting source of the marks and the Greenwich Mean Time as reported in real time.

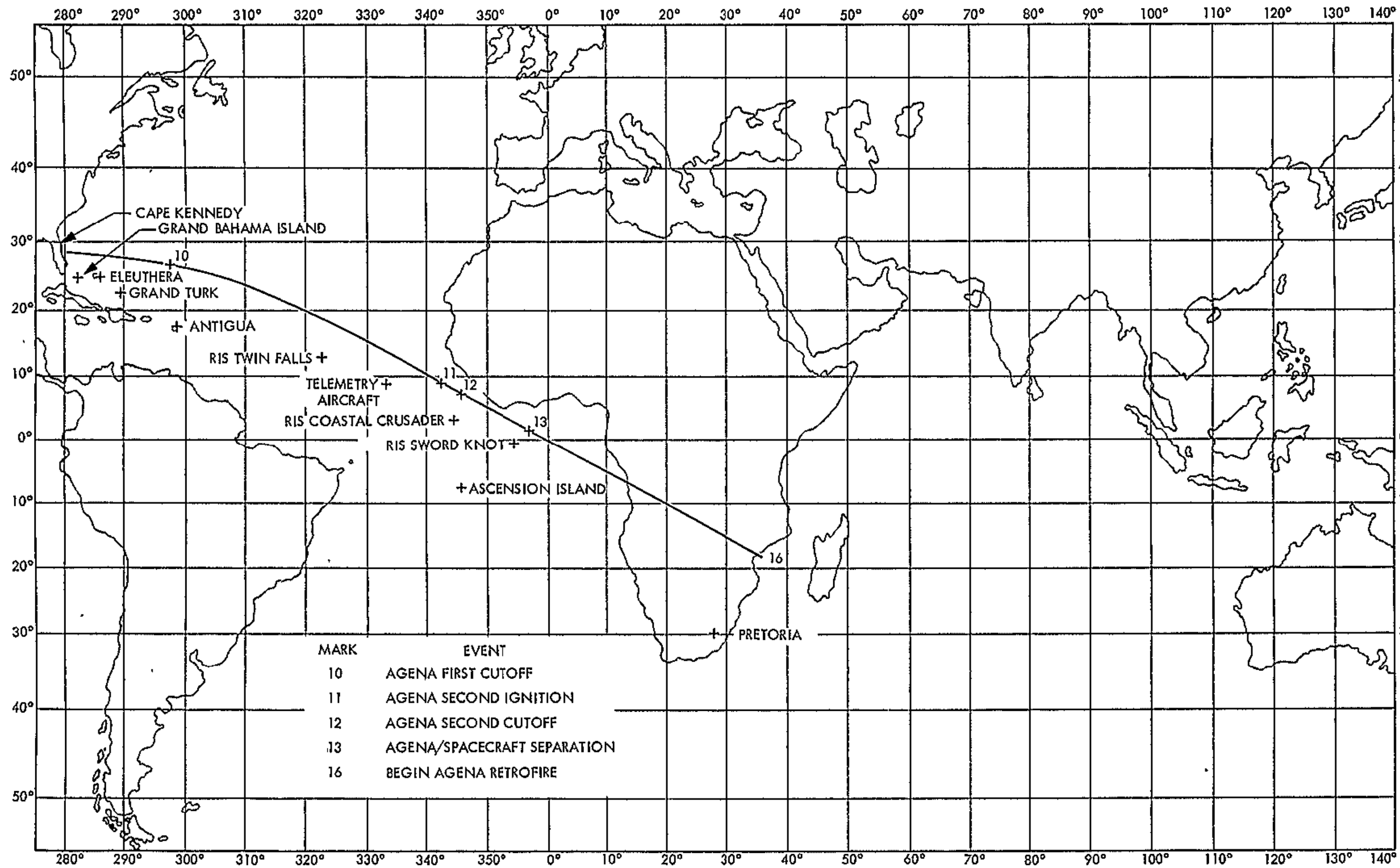

Fig. 37. Mission II near-earth support station locations

Table 17. Mission II nominal mark event time vs actual time

Mark	Event	Time from launch		Report source
		Nominal, s	Actual, s	
1	*Atlas* booster cutoff	129.0	128.2	Tel-2
2	*Atlas* booster engine jettison	132.0	131.3	↓
3	Start *Agena* secondary timer	258.9	269.8	↓
4	*Atlas* sustainer cutoff	287.0	290.7	↓
5	Start *Agena* primary timer	290.1	292.9	↓
6	*Atlas* vernier cutoff	307.2	314.1	↓
7	Shroud separation	309.5	316.6	↓
8	*Atlas/Agena* separation	311.5	318.2	↓
9	*Agena* first ignition	364.3	366.9	↓
10	*Agena* first cutoff	516.4	522.2	Tel-2
11	*Agena* second ignition	1198.0	1199.0	RIS *Sword Knot*
12	*Agena* second cutoff	1284.7	1287.0	RIS *Sword Knot*
13	*Agena*/spacecraft separation	1450.9	1452.0	RIS *Sword Knot*
14	Begin *Agena* yaw	1453.9	1454.8	RIS *Coastal Crusader*
15	Stop *Agena* yaw	1513.9	1514.8	RIS *Coastal Crusader*
16	Begin *Agena* retro-fire	2050.9	2044.8	Pretoria
17	End *Agena* retro-fire	2066.9	2068.8	Pretoria

Table 18. Time of mark events

Mark event	Time, GMT	Report source
First motion	23:21:00.195	Tel-2
1	23:23:08.4	↓
2	23:23:11.50	↓
3	23:25:30	↓
4	23:25:50.9	↓
5	23:25:53.1	↓
6	23:26:14.3	↓
7	23:26:16.8	↓
8	23:26:18.4	↓
9	23:27:07.13	Tel-2
	23:27:07.2	Bermuda
10	23:29:42.44	Tel-2
11	23:29:42.5	Bermuda
	23:40:59.2	RIS *Sword Knot*
	23:40:49	Aircraft
12	23:42:27.2	RIS *Sword Knot*
	23:42:30	Aircraft
	23:42:27.3	Ascension Island
13	23:45:12.0	RIS *Coastal Crusader*
	23:45:12.2	Ascension Island and RIS *Sword Knot*
	23:46:12.5	Kano
14	23:45:14.963	RIS *Coastal Crusader*
15	23:46:14.955	RIS *Coastal Crusader*
16	23:55:05	Pretoria
	23:54:11.9	RIS *Sword Knot*
	23:55:12.2	Tananarive
	23.55:11.8	Kano
17	23:55:29	Pretoria
	23:54:29.5	RIS *Sword Knot*

Launch vehicle telemetry was retransmitted in real time from Antigua to Cape Kennedy and displayed at the Launch Vehicle Data Center at Bldg AE. Real-time analysis of these data was reported to the MOC. A commentary on the range safety plots was also reported in real time. A report based on analysis of the *Atlas* command guidance system performance was made to the MOC from the Guided Missile Control Facility on the injection conditions of the *Atlas* coast ellipse and the start times of the *Agena* timers. This early report indicated that the parking orbit was nominal, and was later corroborated by the first orbit determination performed by the AFETR RTCS. Data for the *Agena* second burn performance analysis was limited to the actual orbits and the reported mark events.

B. AFETR Performance

1. C-band radar metric data. Committed metric coverage versus actual coverage is shown in Fig. 38. All Class I metric requirements were met. The RIS *Twin Falls* failed to provide metric data during its committed interval because of equipment failures; these data, however, were not needed for satisfying Class I requirements. Antigua TPQ-18 Radar managed to transmit 3 min of metric data beyond parking orbit insertion. Bermuda FPS-16 Radar

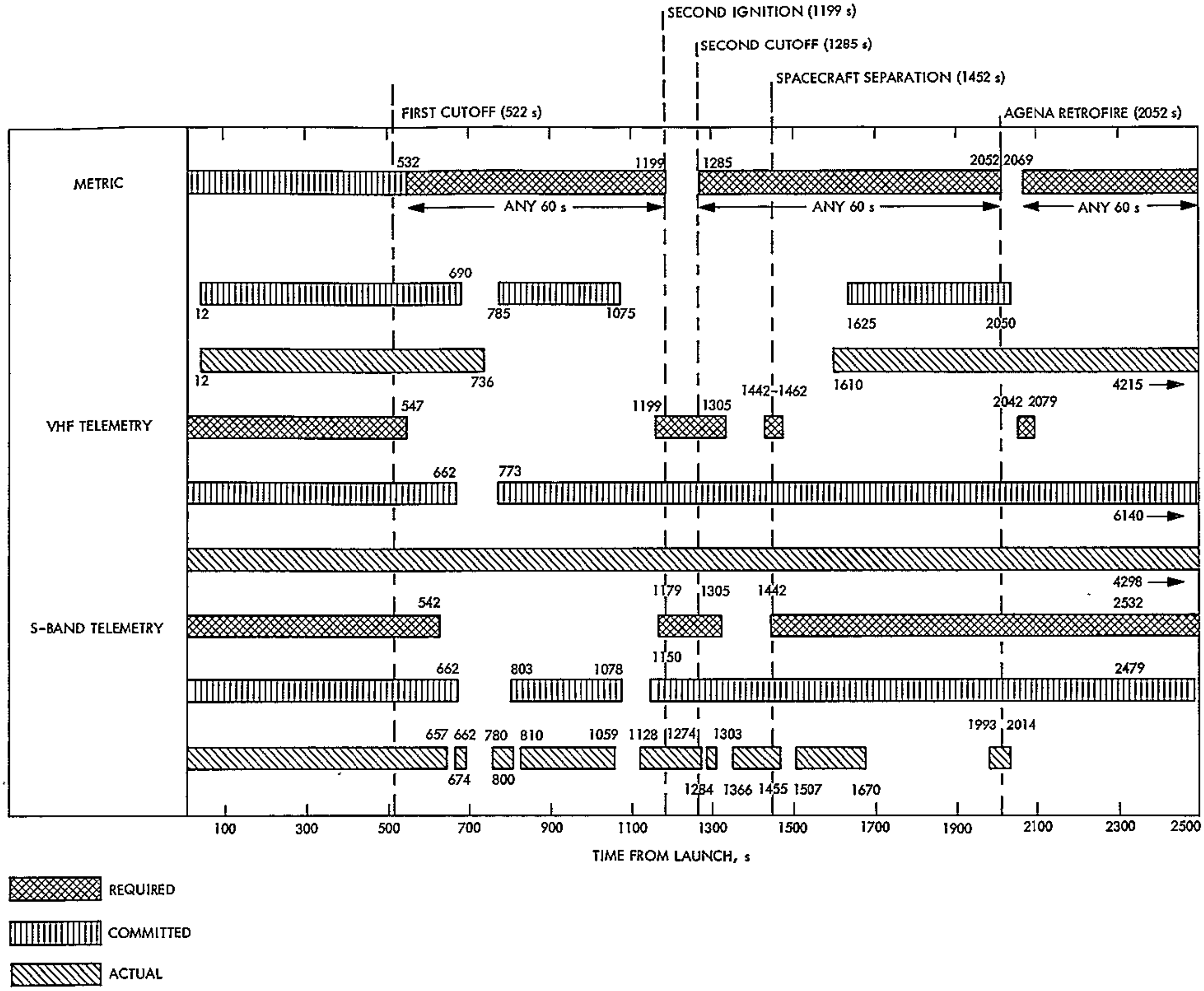

Fig. 38. Mission II AFETR radar metric and telemetry coverage

transmitted about 2½ min, and Grand Turk TPQ-18 Radar about ½ min.

Grand Canary MPS-26 Radar and Ascension TPQ-18 Radar had no view-period for this launch trajectory. Pretoria FPS-16 Radar acquired a signal at approximately $L+27$ min after *Agena*–spacecraft separation, and tracked through *Agena* retrofire, and during the post-retro orbit. The data from Pretoria began breaking up after *Agena* retro, but at a point beyond AFETR committed coverage.

2. ***VHF and S-band telemetry data.*** Expected VHF and S-band telemetry coverage versus actual coverage is shown in Figs. 38, 39, 40, and 41. Class I telemetry requirements were partially met; gaps in S-band coverage with respect to both requirements and commitments are shown in Figs. 38 and 41. Spacecraft telemetry received by way of the 98 kHz subcarrier (Channel F) on the *Agena* VHF (249.9 MHz) telemetry link by the AFETR land stations and ships was successfully retransmitted through Cape Kennedy Tel-2 to DSS 71 and then to the SFOF in Pasadena. Continuous Channel F data were received at Cape Kennedy with the exception of an expected gap between the Antigua land station and the RIS *Twin Falls*. The RIS *Sword Knot* underwent intermittent VHF track during an interval beyond its committed coverage (between $T + 2348$ s and $T + 2793$ s).

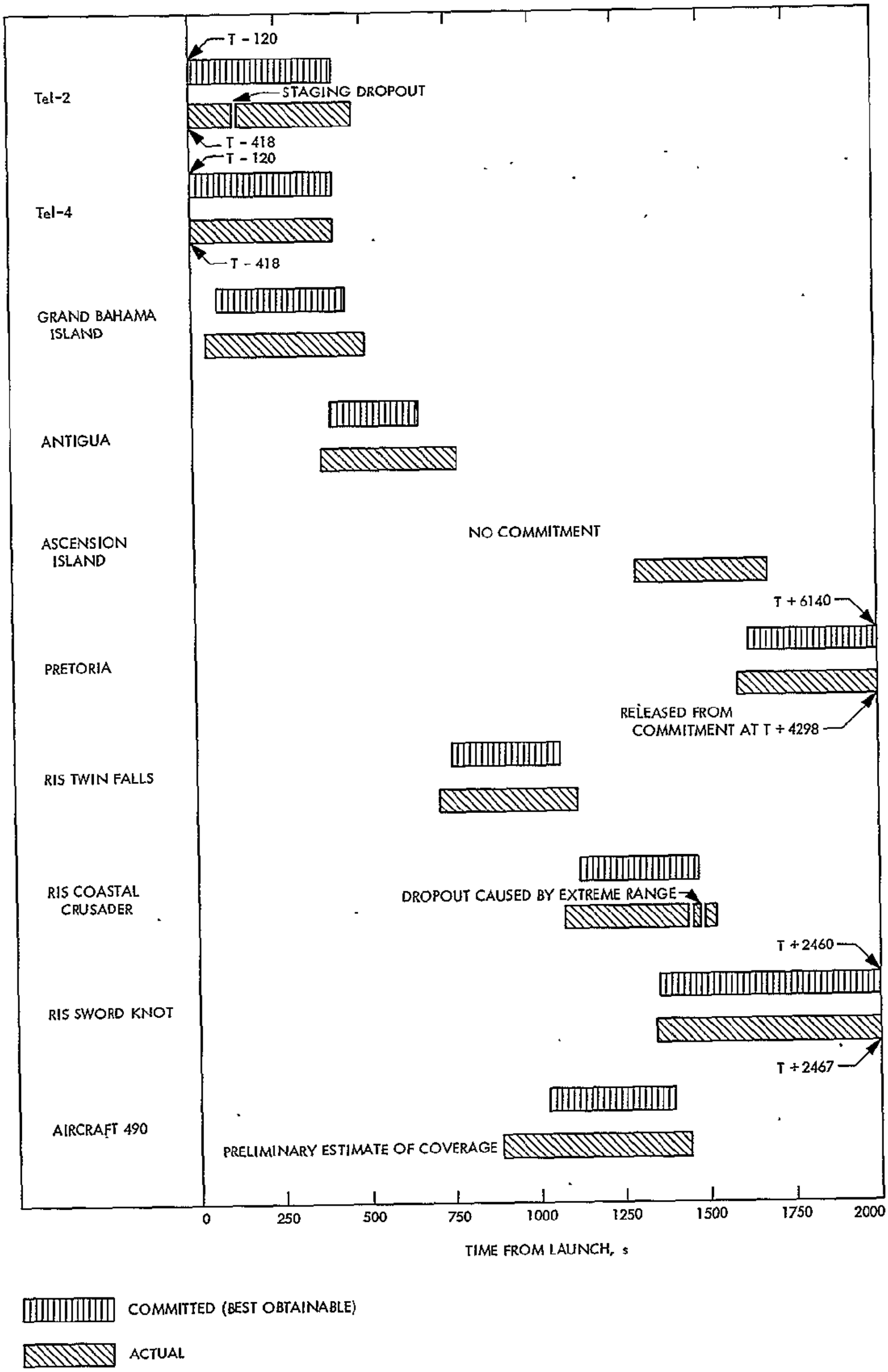

Fig. 39. Mission II-AFETR VHF 244.3 MHz telemetry coverage

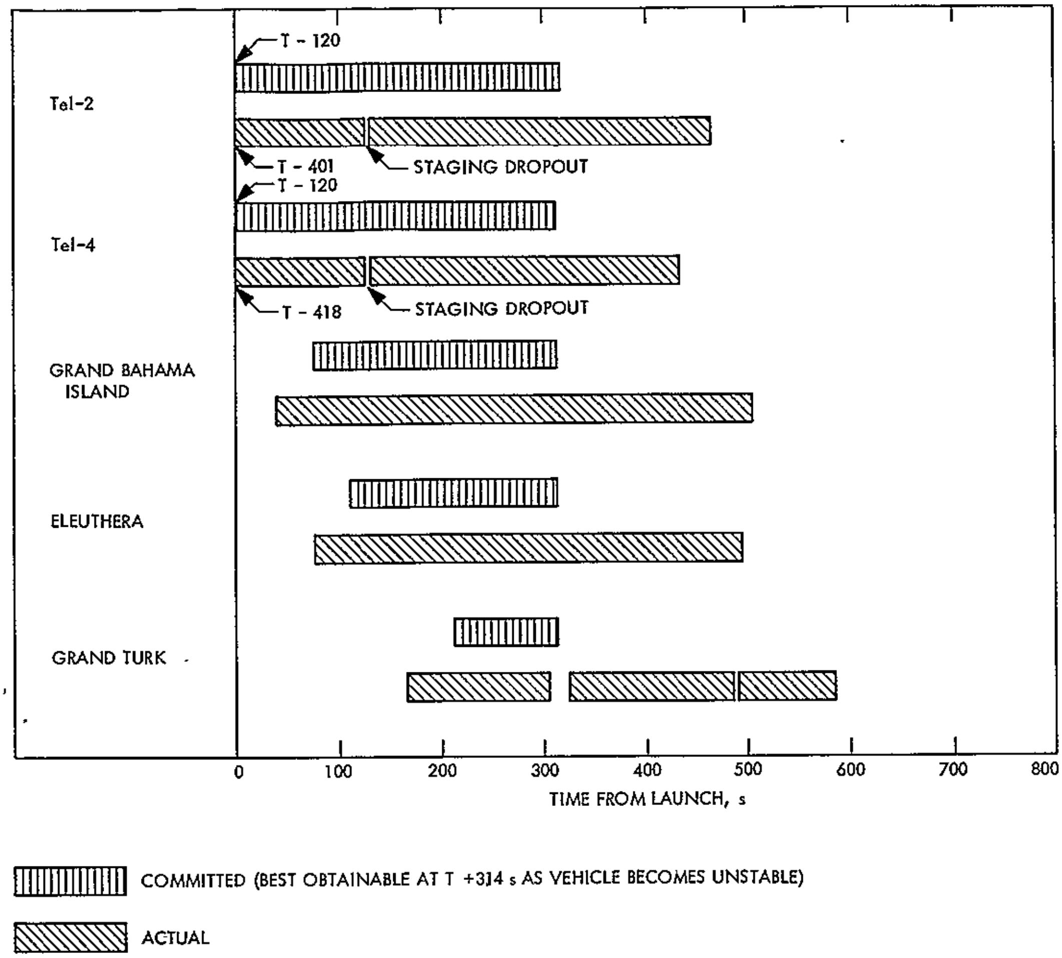

Fig. 40. Mission II AFETR VHF 249.9 MHz telemetry coverage

Cape Kennedy Tel-2 and Tel-4 failed to reacquire the telemetry signal at $T + 343$ s as planned (Fig. 41); this would have provided only redundant coverage, however. Channel F data were selected from the downrange sources and switched to DSS 71 at the times listed in Table 19. The total usable Channel F data amounted to 89.4%.

3. ***RTCS data processing.*** Computations performed by the AFETR RTCS are listed in Table 20. Support was classified as good, and resulted in the generation of accurate orbits early in the mission. Radar metric data were used to calculate the actual parking orbit, the predicted transfer orbit, the actual transfer orbit, and the actual *Agena* post-retro orbit. More descriptive data for these orbits are listed in Table 21.

The RTCS also computed two additional spacecraft orbits from DSS 51 two-way tracking data after two

Table 19. *Agena* Channel F spacecraft telemetry received at DSS 71 for retransmission to the SFOF

Station	From, GMT	To, GMT	Usable data, %
Tel-2	23:21:00	23:24:27	100
Grand Bahama Island	23:24:27	23:27:40	87.5
Antigua	23:27:40	23:33:25[a]	93.2
RIS *Twin Falls*	23:36:00	23:39:39	88.8
RIS *Coastal Crusader*	23:39:39	23:45:12[b]	79.9

[a]Loss of signal.
[b]Spacecraft separation.

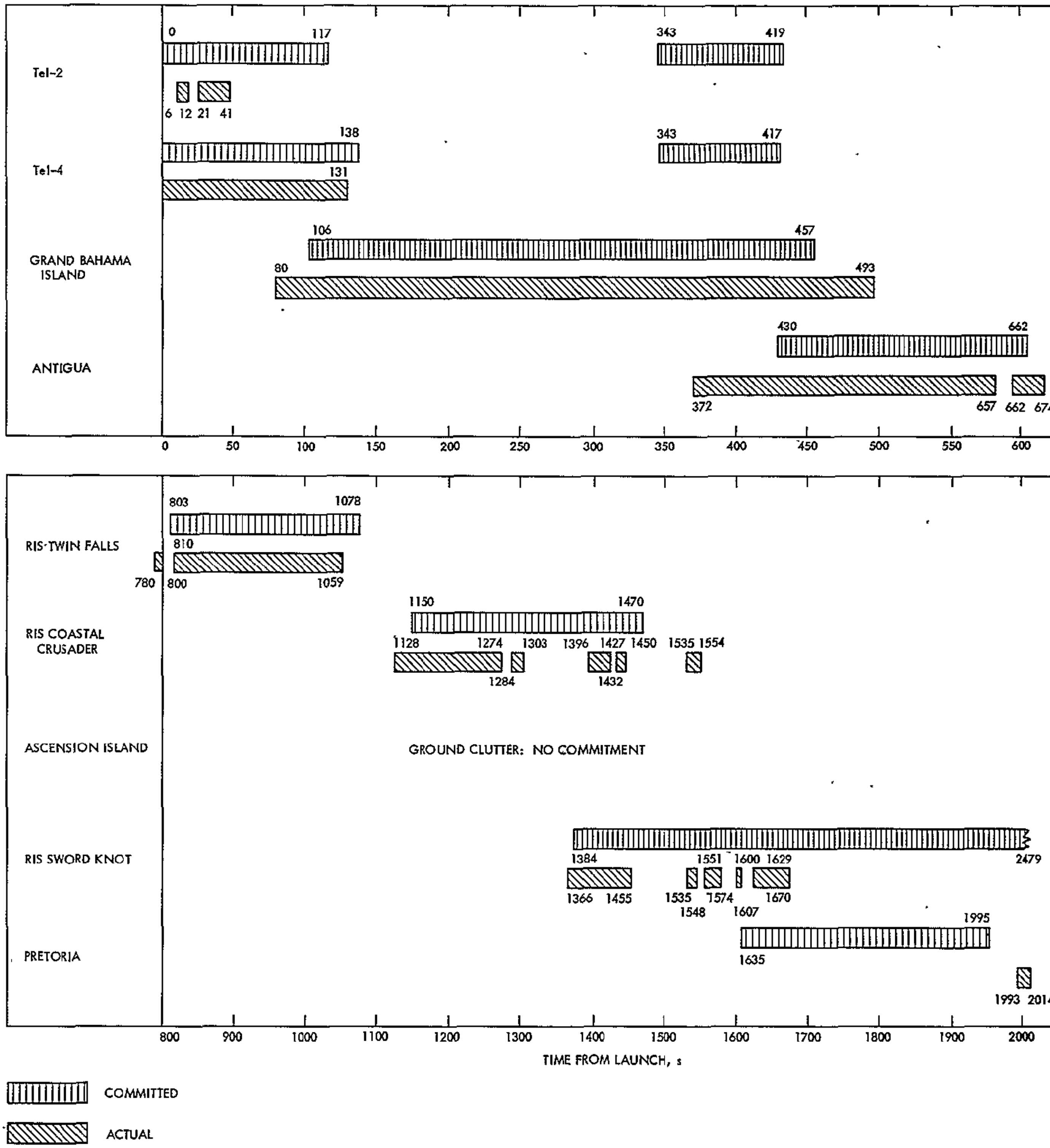

Fig. 41. Mission II AFETR S-band telemetry coverage

Table 20. AFETR Real-Time Computer System performance

Orbit	Epoch, s	Time of computation, s	Data source	Quality
Parking orbit	$T+550$	$T+780$	Antigua	Fair
Predicted transfer orbit[a]	$T+1287$	—	Antigua	Fair
Actual transfer orbit 1[a]	$T+1832$	$T+2520$	Pretoria	Good
Agena post-retrofire orbit	$T+3114$	$T+4800$	Carnarvon	Fair
Actual transfer orbit 2[a]	$T+2340$	$T+5460$	DSS 51	Fair
Actual transfer orbit 3	$T+2340$	$T+11{,}160$	Pretoria, DSS 51	Fair

[a]The RTCS generated predicts from these orbits.

orbits had been rejected as unusable by the SFOF Data Processing System owing to an incorrect preamble in the teletype message header. Usually these orbits are computed by the RTCS only as a backup to the SFOF; but at the request of the FPAC Director, the RTCS was declared the prime data source, and scheduled RTCS operations were suspended until the SFOF could resume its normal data processing functions. The RTCS later used the same DSS 51 data to compute valid DSIF predicts for DSSs 41 and 61.

C. MSFN Performance

1. VHF telemetry and C-band radar metric data. Committed VHF telemetry and C-band radar beacon tracking coverage versus actual coverage is shown in Fig. 42. All requirements were met with the exception of the first 55 s of committed Bermuda metric coverage, which was lost owing to the inaccuracy of antenna pointing data supplied by Goddard Space Flight Center (GSFC).

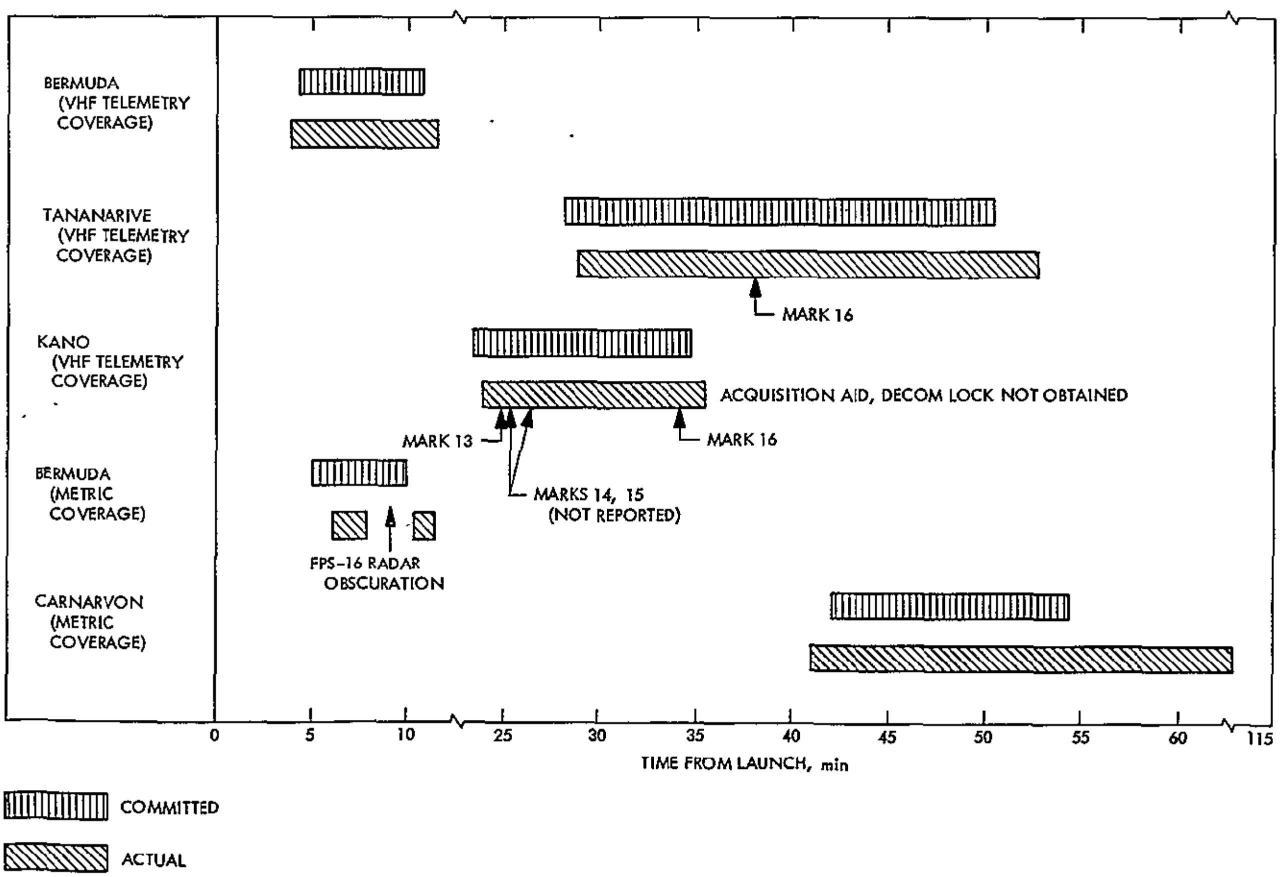

Fig. 42. Mission II MSFN VHF telemetry and C-band radar metric coverage

Table 21. Mission II early orbit determination results

Orbit	B, km	B • TT, km	B • RT, km	Closest arrival, GMT (Nov 10, 1966)	RCA,[a] km
Nominal aiming point from targeting specification or firing tables		6,215	− 596		
AFETR first transfer orbit, from Pretoria (FPS-16) data only	10,235	10,156	−1271	21:17:38	6,174
DSN backup transfer orbit 1101, from 4½ min Pretoria (FPS-16) data only	12,964	12,782	−2167	21:45:45	8,628
AFETR *Agena* post-retro orbit, from Pretoria (FPS-16) and Carnarvon tracking data	37,247	36,752	−6047	23:17:43	32,091
Project orbit 1102, from about 8½ min DSS 41 three-way doppler and angle data only	9,006	8,993	− 479	21:29:59	5,104
AFETR second transfer orbit, from Pretoria (FPS-16) and DSS 51 data	10,239	10,208	− 788	21:16:23	6,178
DSN orbit 1103, from about 12.5 min DSS 51 and 23 min DSS 41 data	10,391	10,280	−1511	21:18:38	6,311
AFETR third transfer orbit, from Pretoria (FPS-16) and DSS 51 data	10,108	10,082	− 725	21:15:52	6,063
Project orbit 1104, from about 22 min DSS 51 and 34 min DSS 41 data	10,522	10,418	−1473	21:21:07	6,426
DSN orbit 1105, from about ½ h DSS 51 and 2 h DSS 41 data	10,541	10,436	−1486	21:21:06	6,443
Project orbit 1206, from about 3½ h DSS 51 and 3 h DSS 41 data	10,530	10,426	−1474	21:21:07	6,433
DSN orbit 1107, from about ½ h DSS 51 and 3½ h DSS 41 data	10,532	10,428	−1477	21:21:05	6,436
DSN orbit 1109, from about ½ h DSS 51, 4½ h DSS 41 data	10,529	10,426	−1473	21:21:07	6,433
Project orbit 1208, from about 7 h DSS 51, 5 h DSS 41, and 2 h DSS 61 data	10,533	10,425	−1474	21:21:07	6,432
Project orbit 1310, from about 10½ h DSS 51, 5 h DSS 41, 8½ h DSS 61, and 2 h DSS 12 data; preliminary midcourse maneuver orbit	10,532	10,428	−1475	21:21:05	6,435
DSN orbit 1111, from about ½ h DSS 51, 5 h DSS 41, 7½ h DSS 61, and 5 h DSS 12 data	10,529	10,425	−1476	21:21:09	6,433
Project orbit 1112, from about ½ h DSS 51, 5 h DSS 41, 7½ h DSS 61, and 7½ h DSS 12 data; midcourse maneuver orbit	10,531	10,427	−1477	21:21:07	6,435
Project orbit 1218, from about ½ h DSS 51, 21 h DSS 41, 7½ h DSS 61, and 7½ h DSS 12 data; late-midcourse maneuver orbit	10,532	10,428	−1476	22:21:08	6,435

[a]RCA means *radius of closest approach*.

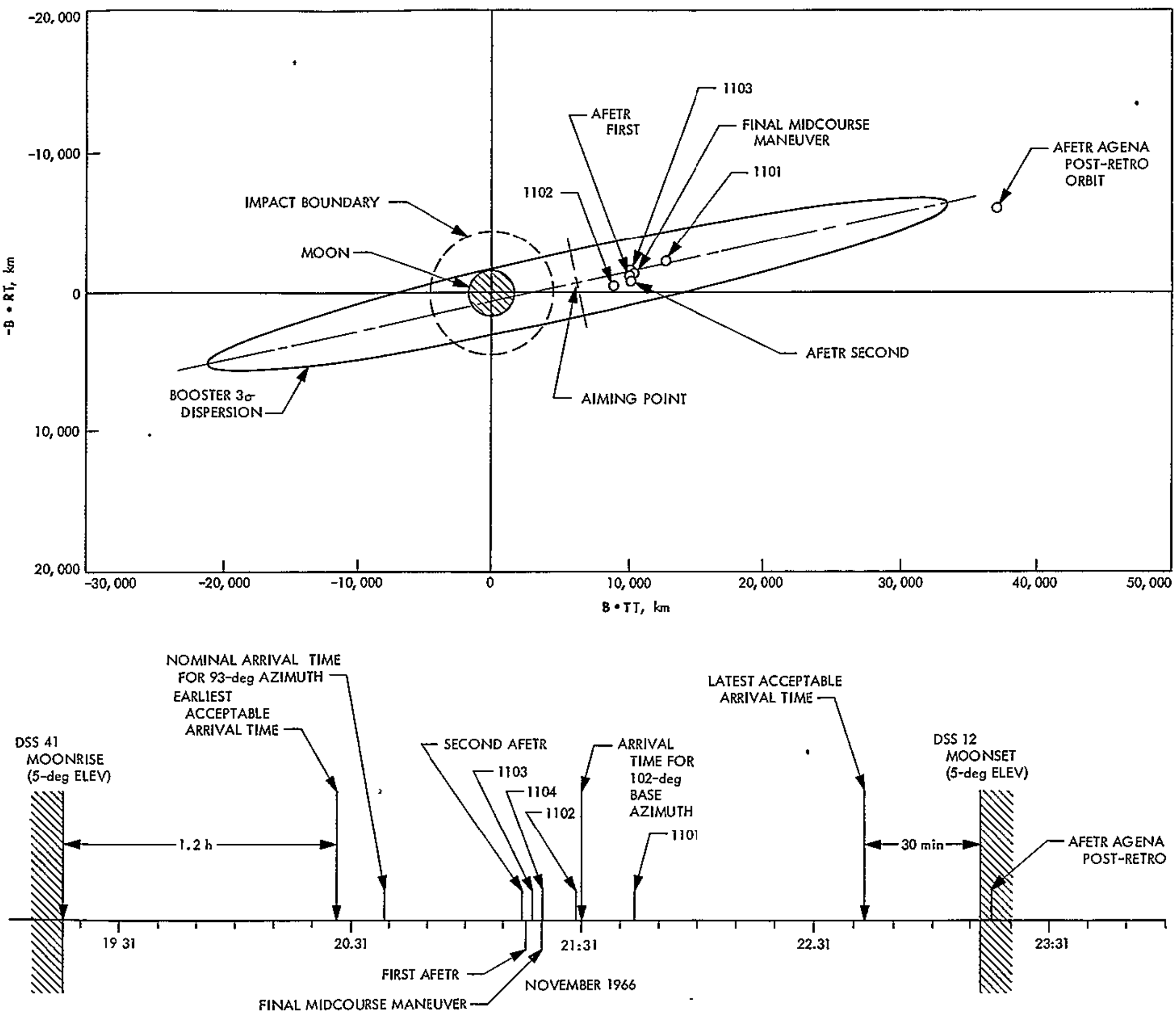

Fig. 43. Mission II early orbit determination B-plane map

2. Data processing and display. The GSFC Data Operations Branch received all AFETR downrange metric data and generated nominal pre-mission antenna pointing data and real-time acquisition messages for MSFN land radars. All required computer support was provided. A new computer program used by GSFC to reformat Carnarvon and Grand Canary radar data failed at approximately $T + 52$ min, causing Carnarvon tracking data to be delayed for approximately 20 min. All Class I metric data required from Carnarvon had been received before this difficulty, however.

D. Ground Communications

The performance of NASCOM during the near-earth phase met all support requirements. All lines were up during critical periods except DSS 41 teletype lines, which went out during DSS 41 initial acquisition.

E. DSN Processing of Near-Earth Tracking Data

1. Raw metric data processing

a. Performance. All Class I support requirements for raw metric data were met. The following summarizes the quantity and quality of raw metric data received by the SFOF DPS.

The RTCS provided an extremely accurate transfer orbit determination from the small amount of Pretoria tracking data. The FPAC team used approximately 4½ min of the Pretoria pre-retro metric data to determine a backup cislunar orbit (Orbit 1101), since none of the expected DSN data was available. (See Figs. 43 and 44, and Table 21 for orbit determination results.) Carnarvon FPQ-6 Radar provided approximately one hour of *Agena* post-retro data. These data (plus the Pretoria post-retro tracking data) were used to determine an *Agena* post-retro orbit.

At Johannesburg, DSS 51 acquired two-way doppler tracking data as expected, starting at station rise plus 5½ min. However, because of problems within the DSN these data were not available to the FPAC team until $L + 1$ h 30 min. At Woomera, DSS 41 acquired two-way doppler tracking data as expected, starting at station rise plus 15 min but, owing to a communication problem, only three-way tracking data were available to the FPAC team until $L + 1$ h 20 min. The Project FPAC team used the limited amount of three-way doppler tracking data obtained before the communication outage to estimate its first cislunar orbit (Orbit 1102). Raw tracking data from DSS 51, Johannesburg, was fed back from the SFOF to the AFETR RTCS and combined with Pretoria FPS-16 Radar data to determine a second cislunar orbit. Data from DSS 41, Woomera, and DSS 51 were recovered and the DSN FPAC team computed Orbit 1103; Orbit 1104 was computed by the Project FPAC team. Additional DSN data was fed back to the AFETR RTCS and used to compute a third cislunar orbit.

b. Problems. Except for the rejection of the early DSS 51 data by the SFOF DPS, there were no significant problems. Although the RIS *Twin Falls* did not provide the expected metric coverage, this did not adversely affect the mission. The inability of the SFOF to process the early DSS 51 data and to resolve the teletype communication problem with DSS 41 caused a delay in obtaining the first good DSN FPAC orbit determination.

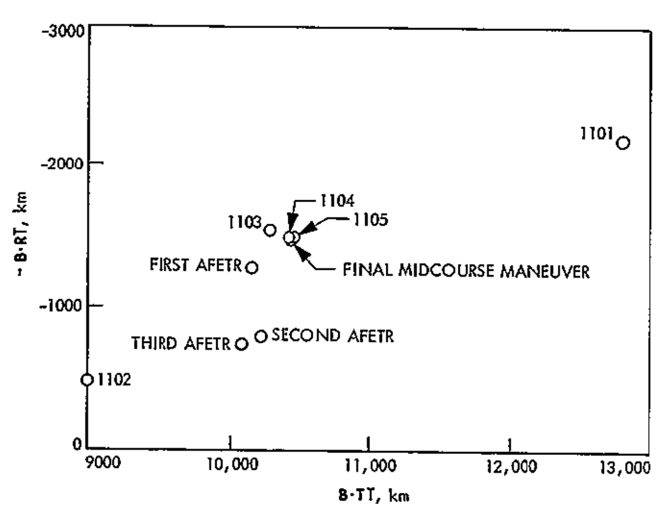

Fig. 44. Mission II early orbit determination results

2. Computed metric data processing

a. Performance. The support requirements for the transmission and processing of computed metric data were successfully met. The following is a summary of the actual performance:

(1) Nominal DSIF predictions, based on nominal injection conditions, were run by the DSN FPAC team, and selected sets of predicts were transmitted to Deep Space Stations 41, 51, and 72. Inconsistency in reports of the expected launch time and launch azimuth caused some confusion and delay.

(2) The AFETR MOC received routine updated nominal mark event times from the Launch Vehicle Center (Bldg AE) but failed to report this information to the FPAC team.

(3) Predict set 02A, based on the AFETR second transfer orbit, was requested from the RTCS in real time, received, and transmitted to DSSs 41 and 51. The predicts were requested because of computational delays caused by the loss of early DSN metric data.

(4) Two additional sets of actual transfer orbit elements and injection conditions based on Pretoria metric data and DSS 51 data were received from the RTCS.

(5) Three sets of actual transfer orbit elements and injection conditions were mapped to lunar encounter.

(6) One set of *Agena* post-retro orbit elements and injection conditions were received from the RTCS, and were mapped to lunar encounter.

b. Problems. The overall performance and efficiency of the DSN FPAC Group was improved over Mission I, but would not have been satisfactory had the mission become nonstandard. Since both launch vehicle and spacecraft performances were nominal, no significant problems were encountered.

A performance analysis at the end of the mission produced the following recommendations for increasing the efficiency of the DSN FPAC team:

(1) Modification of the network countdown to accommodate a revised sequence of FPAC user program checkout cases and to add a Deep Space Station static point test for calibration purposes at $T-2$ h.

(2) Better coordination between the mission analyst at the MOC and the DSN FPAC group flight analyst to improve the flow of necessary information.

(3) Tighter access control in the FPAC area between $L-2$ h to $L+2$ h. No changes to mission-independent personnel on duty during this period.

(4) Improved understanding and performance in the delivery, evaluation, and reporting of critical mission performance information.

IV. Deep Space Operations and Performance Summary

A. DSN Performance

1. General. The DSN commitments to the Project for Mission II were met. Approximately 819 h of DSIF tracking coverage and 1184 h of computer support were provided during the photographic phase. These figures are a significant reduction in support when compared with the photographic phase of Mission I.

2. Scheduling. Requests for the allocation of DSN resources were received in a much more timely manner than with Mission I. Some input data with respect to individual test details were still late, but performance was considerably improved over Mission I.

3. Operations. Nearly all recommendations made after Mission I were put into effect and resulted in a much smoother DSN–Project interface. The position of SNOMAN functioned much more smoothly as the single point of contact between DSN and Project operations. During the picture readout period, the position was satisfactorily manned by the DSN Operations Control Chief instead of the DSN Project Engineer for *Lunar Orbiter.*

4. Configuration control. Only minor changes were made in the DSN configuration between Missions I and II. These were carried out by the same informal control method used during Mission I of joint concurrence of the Project SFO Director and the DSN Project Engineer.

5. Simulation. The use of the Mission I spacecraft as a live tracking and data source for some of the training exercises added a measure of realism to these tests. The SDCC used high-speed data lines to provide a much better simulation of the DSN as a system.

B. DSIF Performance

1. Flight summary

a. Launch and initial acquisition phase. After launch, DSS 71 tracked the spacecraft manually in one-way lock for 3 min 24 s before the spacecraft passed out of range. Up for training purposes only, DSS 72 acquired the spacecraft in one-way lock at 23:42:40 GMT and lost lock at 23:45:00 as predicted. At 23:48:33 (predicted time 23:48:38) DSS 51 acquired the spacecraft and was in two-way lock on the main antenna beam at 23:51:53. The acquisition was accomplished by using preflight nominal predictions, since no spacecraft AGC or static phase error was available as an aid. The uplink frequency for DSS 51 at initial acquisition was within 19 Hz (at the VCO) of the predicted acquisition frequency.

b. Transit and lunar phase. Deep Space Station 41 acquired the downlink frequency and was in three-way lock at 00:12:14; two-way track was transferred from DSS 51 to DSS 41 at 00:30:00. The APS was checked out by the DSIF stations after the midcourse maneuver and was found to operate properly only when the station Interim Monitor Program (IMP) was disabled.

At 02:15:00, DSS 41 initiated ranging operations with excellent results. Clock synchronization between the DSIF stations was performed continually during the transit phase. After injection into the initial lunar orbit at 23:58:42, November 15, 1966, further clock synchronization refinements and ranging were performed to check out the ranging system and to determine the lunar orbit parameters. Except for minor anomalies, the stations functioned exceptionally well during lunar orbit. Approximately 90 s of data were lost during a power failure at DSS 41.

c. Signal levels. The signal levels received at the prime stations are shown in Fig. 45 and vary between 2 and 3 dB, on an average, above predicted nominal values.

d. Station anomalies. The significant anomalies and their causes and effects on the mission are given in Table 22.

Table 22. Mission II summary of DSIF anomalies

DDS	Day, 1966	Time, GMT h:min	Anomaly	Probable cause	Remedy	Effect on mission	Comment
41	312	00:12	Receiver 1 intermittent drop lock	Bad power supply	Switched to receiver 2	None	Random failure
12	313	17:00	Station unable to use IMP	Bad vacuum pump in magnetic tape unit	Replaced motor	None (IMP is mission-independent)	Random failure
61	318	11:15	Unable to tune receiver fine VCO exciter control	Broken bushing	Tuned with course control	None	Random failure
12	321	19:46	Pressure loss in maser refrigeration subsystem	Subsystem circuit contamination	Transferred track to DSS 11	None	Common failure
41	322	12:25	Power failure	Cat crossing station power transformer	Held in circuit breaker to end of pass (10 min)	About 1 min of telemetry lost	Catastrophe
61	322	14:40	Transmitter tripped off	Low nitrogen pressure	Turned transmitter back on	None	Station instructed to keep better watch on pressure
61	323	17:01	Maser failure	Cross-head pump failure	Switched to paramp	None	Common failure
12	324	21:14	TCP failure	Unknown	Switched to backup computer	None	Random failure
61	325	19:10	Ranging readout register failure	Unknown	Stopped ranging		
12	326	03:11	APS failure	Memory parity error	Went to aided rate	Unknown	May be due to IMP initialization
41	326	06:55	APS failure	Memory parity error	Went to aided rate	Unknown	May be due to IMP initialization
41	327	18:00	APS failure	Memory parity error	Went to aided rate	Unknown	May be due to IMP initialization
12	328	07:45	APS failure	Memory parity error	Went to aided rate	None	May be due to IMP initialization

Table 22 (contd)

DSS	Day, 1966	Time, GMT h:min	Anomaly	Probable cause	Remedy	Effect on mission	Comment
12	329	03:46	Command transmission halt	MDE command subsystem	Commanded by tape loading TCP	None	Random failure
41	330	20:21	Receiver 2 in/out lock isolation amplifier failure	Unknown	Replaced isolation amplifier	None	Random failure
12	332	00:20	Maser failure	Subsystem circuit contamination	Switched to paramp	None	Common failure
61	332	02:40	APS failure	Memory parity error	Went to aided rate	Unknown	May be due to IMP initialization
61	332	20:22	APS failure	Memory parity error	Went to autotrack	None	May be due to IMP initialization
61	332	22:13	Transmitter tripped off	Beam over voltage	Reset beam voltage	None	Random failure
41	334	17:25	GRE 6 failure	Blown fuse	Replaced fuse	None	Random failure
41	335	Precal	Digital Instrumentation System alpha computer failure	Magnetic recorder	—	None (mission-independent)	Random failure
61	338	10:45	Digital Instrumentation System alpha computer failure	Tape transport vacuum motor failure	Replaced vacuum motor	None (mission-independent)	Random failure
12	338	Precal	Moisture in transmitter waveguide	Rain	Purged waveguide	None	Random failure
12	339	07:05	Maser failure	Subsystem circuit contamination	Switched to paramp	None	Common failure
12	339	11:48	APS failue	Memory parity error	Switched to aided rate	Unknown	May be due to IMP initialization
41	340	03:36	Low-speed servo failure	Servo amplifier	Replaced servo amplifier	None	Random failure
12	340	11:47	APS failure	Memory parity error	Switched to aided rate	None	May be due to IMP initialization

2. ***DSIF operations.*** Overall DSIF operations performance was satisfactory. The commitment for 866.5 h of tracking was based on a 31-day photographic mission. The DSIF tracked a total of 819 h before the spacecraft traveling wave tube failure on December 7. The tracking total amounted to 94.5% of the commitment. No major operator errors or major equipment faults occurred during the mission. The total coverage provided during the photographic and extended mission phases is summarized in Table 23.

The operational procedures used during Mission II were the same as those used during Mission I, with the following exceptions:

(1) Command procedures were modified to eliminate confusion that occurred during Mission I command periods.

(2) A new spacecraft high-gain antenna mapping procedure provided realistic signal level information as a function of spacecraft orientation.

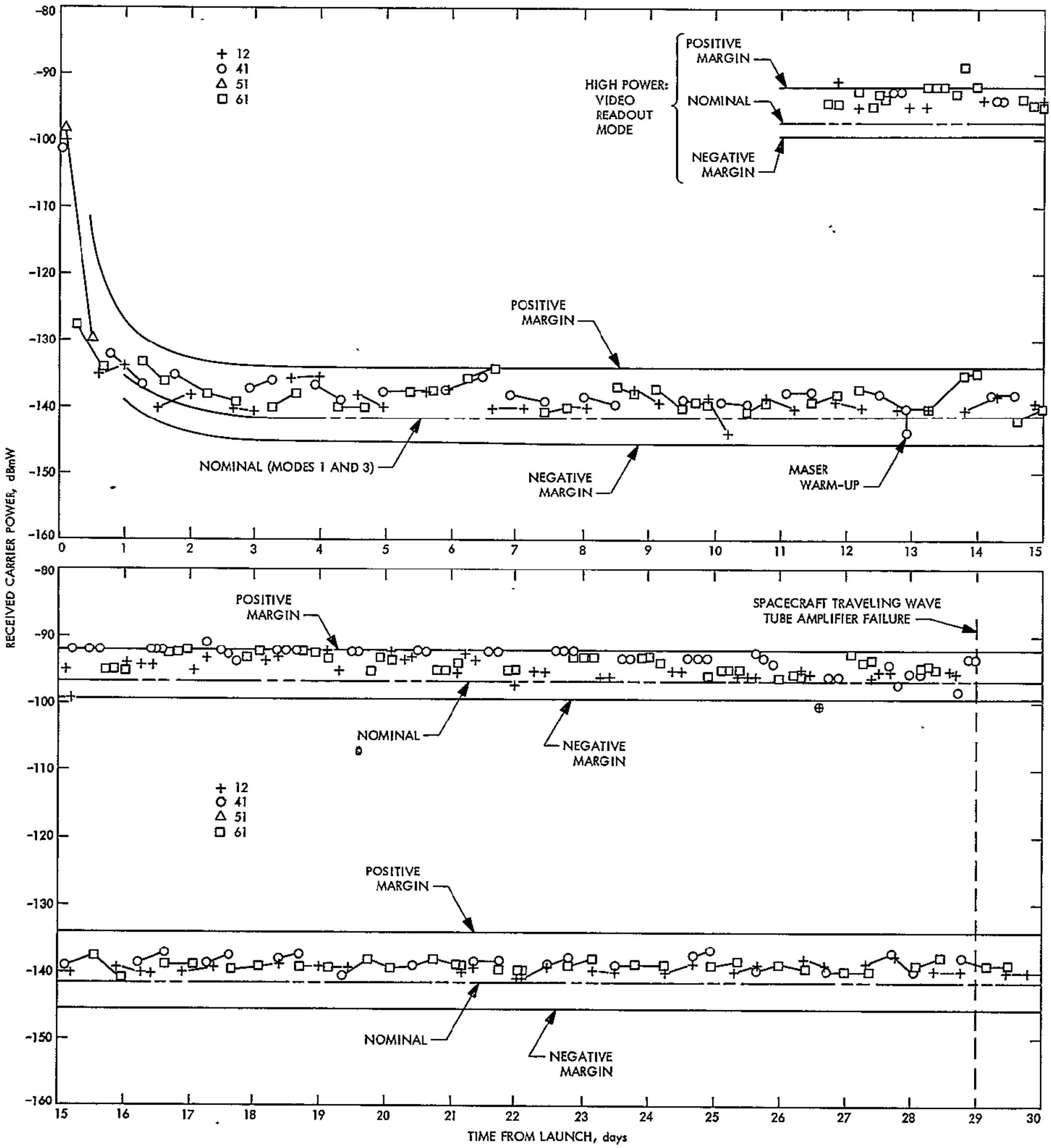

Fig. 45. Mission II received signal strength

Table 23. Total DSIF coverage summary for Mission II photographic and extended mission phases

DDS	Two-way tracking, h	Three-way tracking, h	Total tracking, h	Ranging, h	Time correlation, h
11	5.73	0.00	5.73	2.21	0.00
12	430.13	92.21	522.34	106.26	0.33
41	496.05	91.27	587.32	172.24	0.33
51	0.68	10.83	11.51	0.00	0.00
61	256.37	30.77	287.14	65.38	0.16
62	105.99	19.57	125.56	22.01	0.66
Total	1294.95	244.65	1539.60	368.10	1.48

(3) Time correlation experiment procedures were revised to allow DSIF Net Control to coordinate activities between the stations. No problems were encountered.

(4) Improved understanding of responsibilities between the Project SFO Director (ACE-2/DEUCE-2) and the DSIF Track Chief provided a major improvement in the flow of status information to the Project.

3. *Tracking data analysis*

a. Performance summary. The DSIF SDA Group provided round-the-clock support from launch through the end of the photo exposure phase of the mission and on a one-shift-per-day basis until completion of photo readout. The Group's function was to provide liaison and coordination between the Deep Space Stations where the tracking data originates and the DSN and Project FPAC groups who are the data users. The Group activities included tracking data monitoring and data quality assessment for the FPAC Orbit Determination Group, frequency data to the Orbit Determination Program (ODP), acquisition predicts to the Deep Space Stations, and consultation with the DSIF Operations Engineering Group on the solutions to problems.

The overall performance of the DSIF tracking data system was improved over Mission I. New operational procedures were established and some new software was added at the stations:

(1) Ranging data were taken earlier and more frequently than during Mission I, providing the ODP with another data type.

(2) Time correlation experiments were carried out more frequently.

(3) Acceptable doppler data were obtained during the photo readout phase by using Receiver 2 in an AGC mode even though the RF carrier was deviated more than 2.4 rad; this technique produced usable doppler data during a time that was essentially unproductive for orbit determination purposes during Mission I.

(4) The APS was used at all stations for most of the lunar orbit phase.

(5) The DSIF IMP was used at all stations to permit each to evaluate its own performance and to alert DSN and Project operations to any malfunction.

b. Predicts generation. Predicts were generated at various times depending on the availability of improved state vectors from the ODP. Overall, predicts were more reliable than during Mission I owing to improved lunar harmonic coefficients and to corrected occultation time computation. At their worst, predicts were off by +300 Hz in doppler and about 30 s in occultation times during the lunar orbit phase. There were no predict outages, although predicts arrived twice at the stations only minutes before use. This delay was due to malfunctions in computer hardware and software, which lengthened the computation beyond expectation. There was no loss of data, however.

c. Tracking data handling. Tracking data handling was satisfactory throughout the DSIF. The notable exception was the real-time loss in the SFOF computer of the DSS 51 first pass data because of an incorrect teletype switching preamble. The data were recovered, however.

d. Tracking data monitoring. The overall performance of the Tracking Data Monitor (TDM) program was greatly improved over Mission I because of a significant reduction in the number of teletype garbles in the input. The program was sensitive to blunder points and the reduction of garbles greatly improved performance. In the translunar phase the TDM generates its own predicted quantities by means of an internal trajectory subprogram. In this phase the predicts are accurate and the residuals remain less than 1 Hz. The computed noise was less than 0.1 Hz, confirming that the data were of high quality.

Figures 46 through 49 show the result of SDA monitoring of spacecraft velocity maneuvers. The plots were completed within 3 min of real time and confirmed that the maneuvers were nominal. The midcourse and transfer maneuver plots (Figs. 46 and 48) were obtained by plotting the TDM residual for the actual data minus predicts that did not include a maneuver. The transient in the residuals was of the same magnitude as the expected change in doppler, and occurs at the time of burn. The injection plot (Fig. 47) shows the TDM residual of the doppler data minus predicts that included the predicted burn. The slight deviation from a straight line during the time of the burn reflects inaccuracies in the predict program burn model.

The curve of the orbit inclination change (Fig. 49) was obtained by plotting the incoming data along the predicted burn. The plot shows a slight bias in the pre-

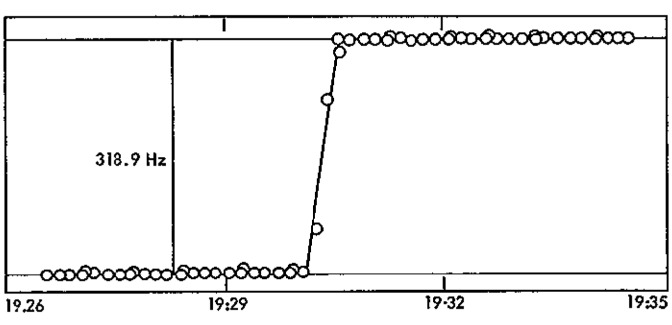

Fig. 46. Mission II midcourse maneuver doppler shift

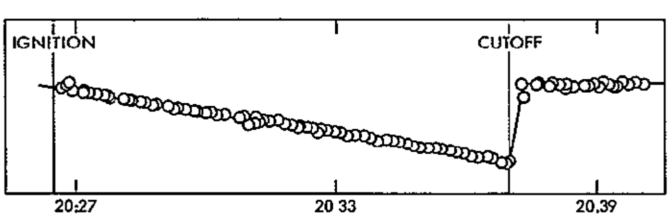

Fig. 47. Mission II orbit injection maneuver doppler shift

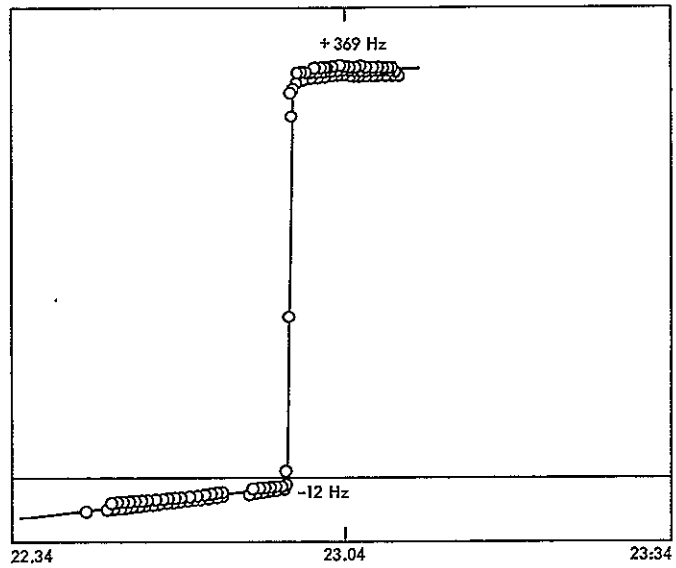

Fig. 48. Mission II transfer maneuver doppler shift

dicts but the shape of the curve is the same in both cases, showing that the burn was nominal.

e. Problem areas. Problem areas during the mission were as follows:

(1) The preflight nominal predictions supplied by Boeing contained some errors in format and accuracy. The predicts were used successfully, however.

(2) The IMP incorrectly computed doppler residuals when the doppler shift was negative. In addition, the program required the insertion of alarms for the doppler residual computation. These alarms were difficult to estimate correctly during the lunar orbit phase when predict inaccuracies were large.

(3) To bypass problems in the Tracking Data Processor (TDP) and Orbit Data Generator (ODG) programs, the Orbit Determination Group requested that the stations manually insert a good data condition code. This practice was discouraged because it defeated the purpose of the data condition code.

(4) Not all stations used uniform procedures for obtaining doppler data on Receiver 2 during photo readout; this resulted in some degradation or loss of data.

(5) New procedures, which deleted transmitter frequencies from the post-track reports, hampered the checking of doubtful frequencies. However, none of these problems were significant enough to

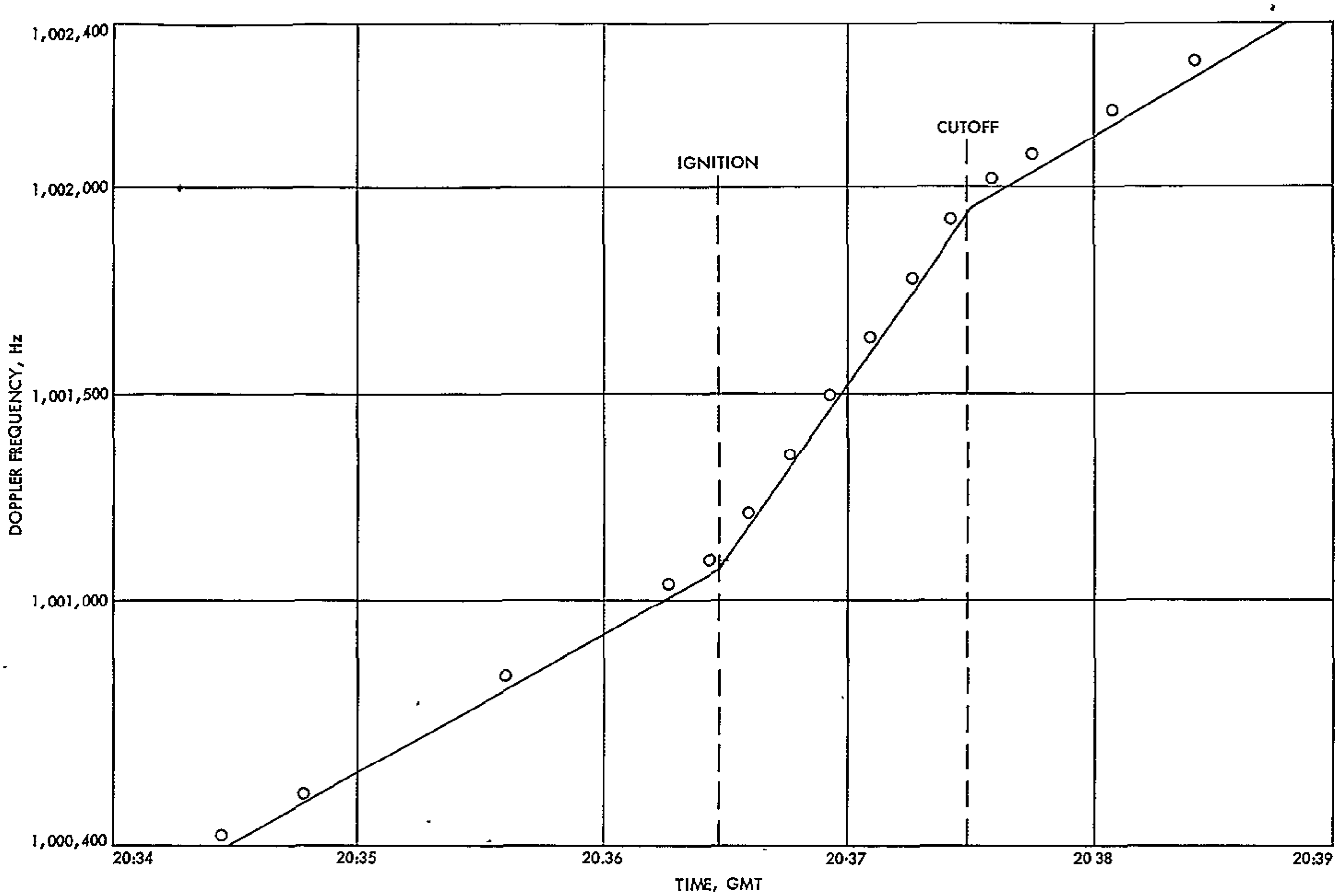

Fig. 49. Mission II velocity maneuver orbit inclination change

jeopardize the retrieval of tracking data. In general, the DSIF tracking data system performed well.

4. *Ranging and time synchronization*

a. Ranging operations. Mission II provided an opportunity for analyzing the value of ranging data as a data type early in the mission. Data were obtained continuously during most of Mission II except during command and photo readout periods, and proved especially valuable in reestablishing the orbit after a motor burn. Since the length of the range unit is determined by the exciter frequency, ranging data provided a sensitive tool for ensuring the use of correct exciter frequencies in the Orbit Determination Program.

The ranging code phase reversal in the Mission II spacecraft transponder caused the ranging data to indicate the range as a one-half modulo number greater than the actual range. A one-half modulo number is approximately the distance to the moon, or exactly 392,881,104 range units. The anomaly was compensated for by adding this amount to the internal spacecraft and ground station delay values which were then removed from the data in the ODG program. Owing to the magnitude of the number, precision was lost in subtracting the number (on the order of ten range units, where one range unit is about 1.04 m). Efforts were made to preprocess portions of the data for postflight analysis (where the bias could be removed) by using more precision than the ODG program was capable of, before reading the data into the TDP–ODG–ODP system or programs.

The standard deviation in the data noise level appeared slightly less than that observed during Mission I. The noise level varied from a low of 2 m to a high of 10 m. Since the level rose as the spacecraft went into lunar orbit, the 10-m figure was assumed to be the sum of orbit uncertainty, program numerical significance problems, and ranging system noise. Range data could not be processed in the TDP if the data condition code indicated the antenna angles as not usable. Since angles were not usable as a data type when the antenna was computer-driven (as during photo readout), it became necessary to use several real-time control cards so that range data could be processed during these periods.

b. Station time synchronization. Time synchronization consisted of measuring the time difference between the DSIF station master clocks. The technique is that of measuring the difference between a 1 pulse/s signal generated by the DSS clock and a commonly received synch pulse used for the range code. These measurements were very successful during Mission II, with data taken in such a manner that the measurement of the station clocks was accurate to within 50 μs, or better, with each other during the first 35 days of the mission. Accuracy during the photo readout phase was probably not so precise, because of the longer time periods between synchronizations. Data were gathered from December 7 through 10 for a special experiment to demonstrate the repeatability and accuracy of using the ranging system for time synchronization. The effort was well supported by both the Project and the DSN. These data were supplied to both the DSN FPAC Orbit Determination Group and to the Project for use by the selenodetic experimenters. In addition to using the ranging system for time synchronization, a special recording procedure for monitoring the station Frequency and Timing Subsystem for possible failure was put into effect.

C. GCF/NASCOM Performance

1. Performance summary. The GCF/NASCOM performance during Mission II was again consistent and highly reliable. High-speed data lines, teletype, and voice lines were exceptionally reliable during all phases of the mission. As expected, the DSS 51 circuits were the least reliable because of high frequency radio propagation conditions. Reliability for DSS 51 teletype and voice lines was 89.6 and 94%, respectively. The DSS 12–SFOF microwave circuits operated by Western Union Telegraph Company continued to furnish virtually 100% reliability. NASCOM arranged for and provided special circuit guards, circuit maintenance, and restoration capabilities at all NASCOM switching centers and commercial carrier terminals around the world during all critical mission periods. This special effort undoubtedly contributed greatly to the extremely high circuit reliability.

2. NASCOM data sets. The use of NASCOM 205B data sets during the critical phases of Mission II proved to be highly successful, and high-quality data from all stations were received; some minor outages were reported, however. Minor procedural problems were evident during the tests, especially in the use of the regenerative mode and during bit rate changes at NASCOM en route to the switching centers.

D. SFOF Performance

1. Data Processing System. The DPS 7044 and 7094 computer strings successfully processed all high-speed data received from the TPS and all teletype data received from the JPL Communications Center as well as all input material and requests received from input/output devices in the user areas. The *Lunar Orbiter* software system for Mission II was essentially the same as for Mission I.

a. Central computing complex. As during Mission I, the most significant problems were those of communication errors between the 7044 and 7094 computers, which caused system failures and loss in computer time. Approximately 2 min were required for recovery from each failure. All data received were processed, however. The error problem, located after Mission IV, was found to be a wiring error in the 7044/7094 system.

In general, hardware performance was again very reliable. Intermittent problems with the 1301 disk files consisted primarily of format, voltage regulation, and parity errors. Several tape drive irregularities were corrected without difficulty.

b. Telemetry processing station. Using digital phone line formatters (DPLF), the TPS successfully processed all high-speed data received from the DSIF stations. The DPLF monitoring equipment (oscilloscopes and counters) and sync functions were used to provide a quality evaluation of the raw telemetry data stream. Two minor equipment problems were quickly corrected; there was no apparent effect on data flow.

c. Input/Output. Overall system performance during the mission was adequate. The most significant problem was an inability to accomplish program control when attempting to enter control parameters through the input devices. These occurrences were infrequent, however, and resulted from equipment malfunctions and occasional software failures. The system was sufficiently redundant to circumvent the occasional failures so that no serious delays were encountered.

2. Staffing and training. Support for the DACON position was furnished by Boeing. The staff, although new for Mission II, had functioned as "system monitors" during Mission I and thus presented no training problem. System monitors on duty during Mission II received valuable training in DACON procedures. Documented procedures were available for Mission II and were issued to the system monitors as well as to each DACON.

3. ***SFOF operations.*** Operational performance was good, and was improved over Mission I. Procedural problems and operator errors were minor and had little or no effect on the success of the mission. An operator failed to reset the 7094 computer printer board clock at the end of the day on November 19, thus causing the wrong day to be printed on all output; an output tape was broken during removal from the tape unit. Other isolated failures and problems were resolved without difficulty.

E. DSN FPAC Performance

1. ***Performance summary.*** Tracking data quality reports were made consistently throughout the active time of the mission (i.e., until the end of the photo readout or the beginning of the extended mission for selenodesy). The data quality was excellent, surpassing DSN performance during Mission I. There were fewer irregularities, and teletype data received at JPL was cleaner and much more usable, not only because of the obtaining of two-way and three-way doppler and ranging throughout, but also because of good spacecraft performance (i.e., no *Canopus* sensor problem as experienced during Mission I). All FPAC recommendations made at the conclusion of Mission I were put into effect with satisfying results.

Ranging data, being sensitive to input frequency error, proved a useful barometer for "doppler-only" orbit determinations, and also gave a measure of position bias on each orbit determination. Ranging data residuals verified the Eckert corrections to the lunar ephemeris which amounted to as much as ±1 km for Mission II. (See Fig. 50.)

2. ***DSN tracking data quality determination.*** The DSN and Project FPAC user program prelaunch checkout cases were successfully completed in support of the

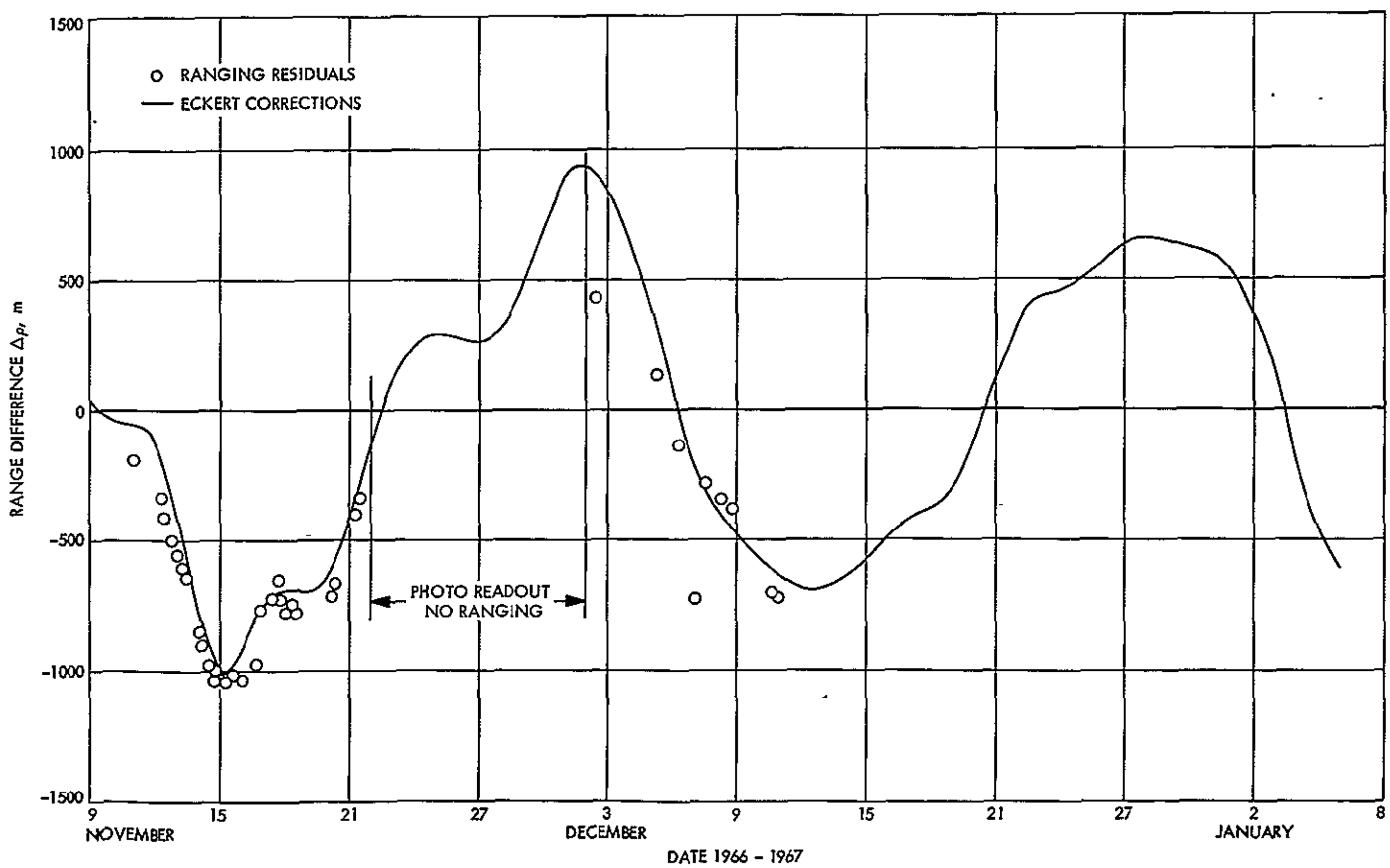

Fig. 50. Mission II ranging data residuals compared with Eckert radial corrections to the lunar ephemeris

November 6 launch. The checkout cases were run by the FPAC team at times different from those indicated in the network countdown; this variation in schedule caused some concern to the mission operations team at times.

Although the orbit determination process was a DSN responsibility during the first 6 h from launch, both DSN and Project personnel collaborated in generating the first orbit determination. The near-earth orbits were generated on schedule and showed a nominal injection, which was subsequently verified by later Project orbit determination computations. The initial deep space phase orbit determination based on DSS 51 data was over an hour late because of an improper teletype address that caused the SFOF DPS to reject the data. The AFETR data from Pretoria was substituted and an acceptable orbit estimate was produced as an input for predicts generation. The AFETR and the RTCS provided exceptional nonstandard support during this period. Angle data from DSS 41 were used until DSS 12 rise and the consistency of the DSS 61 three-way doppler assured the accuracy of the orbit. The low amplitude (0.03 Hz), 30-min periodic error seen in the three-way doppler data from DSS 61 during Mission I was not visible this time. Ranging data were also taken during this phase and comparisons of position estimates made from doppler-only calculations showed only 25-m discrepancies with a high frequency noise of approximately 2 m, caused primarily by the single-precision calculations in the orbit program. All data used for the midcourse maneuver orbit determination calculation were evaluated in the TDQD and assessed as good.

During the postmidcourse phase, long arc fits (i.e., 40 h or more of data) were consistent in all data types. During this phase the use of ranging data first helped remove some input frequency errors. At various times the stations would change transmitter frequencies by 10 to 20 Hz. This would cause a jump in the doppler residuals of 0.01 or 0.02 Hz, which was barely discernible, being on the order of the high-frequency noise. When ranging data residuals were analyzed, jumps of 130 to 260 m were disclosed, indicating that some of these frequency changes were not being reported or were not being inserted in the program. Each occurrence was directly traceable to a frequency error.

After injection into the initial lunar ellipse, ranging data again showed its usefulness. The first lunar orbit determination contained biases in the range of several kilometers along with a definite skewing of the residual plot, indicating a poor estimate. These estimates gave parameter values slightly off the planned values (e.g., orbit after motor burn). However, when more data were added to the fit, the ranging residuals dropped to 100 m and were no longer skewed. The estimates also were much closer to the predicted values. It was concluded that approximately 12 h of data would reestablish a good orbit in the lunar orbit phase. The ranging data also did a fine job of verifying Dr. Eckert's corrections to the lunar ephemeris. As shown in Fig. 5 there is only a 100-m departure from the Eckert correction and the range residual obtained from the uncorrected lunar ephemeris.

During Mission I, doppler data taken during the photo readout phase was unusable. By using the station second receiver, tracking data taken during the Mission II photo readout phase proved to be acceptable. The noise level was approximately a factor of 5 higher than normal (because of the large carrier phase deviations during photo readout), but there was no detectable bias and good orbit estimates were obtained. Toward the end of the photo readout phase some difficulty was encountered in obtaining good convergence. This was not attributed to the data quality; when convergence was obtained, data residuals were normal and consistent. Suspected causes of this convergence problem were (1) a strong potential effect created by the low orbital altitude (i.e., 27 km altitude as compared with 50 km), and (2) possible poor partials near pericenter passage causing a singularity, along with the choice of epoch for initial conditions.

Since data taken near pericenter still cannot be fitted to a random noise level and its use introduces unknown biases, the policy of omitting pericenter data (20 min each side of pericenter) was used throughout the mission. Estimates and predictions based on orbits determined without pericenter data were a factor of approximately 2 better than those with pericenter data. This does not mean to imply that pericenter data are not desirable; it is important data for selenodetic reduction and, once a handling technique is developed, will be used during subsequent missions.

3. *Problems, comments, and recommendations*

a. Scheduling. Considering Mission I experience, the recommendation to request computer time for TDQD only when required instead of specifically scheduling it worked out very well. The schedule was not bogged down with heavy TDQD requirements, and there was no need to cancel computer time or generate work to justify the allocation.

b. Hardware. The rejection of the initial DSS 51 data by the SFOF DPS delayed critical DSN orbit estimates at injection by over an hour. The rejection was not so much a hardware failure as a procedural problem caused by using an incorrect teletype switching code (preamble) in the message header. On two other occasions over 12 h of tracking data were lost. The data were replaced by using backup tracking data recorded on IBM cards as an input.

c. Data accuracies and coverage. Tracking data quality was satisfactory and met all commitment requirements. Data accuracy was approximately 0.01 Hz for a 1-min continuous-counted doppler sample when not in the photo readout phase, and approximately 0.05 Hz in the readout phase. The noise level of the ranging data taken near the earth was approximately 2 m (standard deviation) and approximately 10 m at the moon. Coverage was excellent.

F. Telemetry Data Validation

1. Performance summary. Mission II served to inaugurate the newly formed DSN Monitor System. Support was limited to telemetry data validation, and the mission was used primarily to train and familiarize Monitor personnel with DSN and mission operations. Support began at $L-6$ h and continued around the clock for 31 days until the conclusion of the photo readout phase on December 7, 1966. Validation was limited to teletype telemetry data as received directly from the JPL Communications Center. All teletype telemetry data received at the SFOF was monitored for the following:

(1) Proper synchronization.

(2) Proper number of lines per edit mode.

(3) Proper line length.

(4) Proper number of frames between preambles.

(5) Proper Δt between frames.

(6) Correct Greenwich Mean Time.

(7) Operation of spacecraft clock.

(8) Discrete parameters within the frame.

(9) Parity errors.

All discrepancies were logged according to pass and station and categorized as a Project or a DSN responsibility. In addition, a DSN status board was updated after each pass to display individual station performance with respect to the amount of data transmitted by the spacecraft versus the amount recovered by the DSN. The on-duty DSN monitor analyst maintained voice communication with the SNOMAN, and notified him of significant anomalies that would jeopardize data recovery. Table 24 shows the DSN telemetry performance by station.

2. Conclusion. During all passes, except for the initial pass over DSSs 41 and 61, over 95% of the data transmitted by the spacecraft was recovered by the stations, transmitted by teletype circuits to the SFOF, and displayed in the DSN Monitor Area on teleprinters, all without error. In evaluating the data received, the majority of the discrepancies were attributed to the GCF as parity errors. However, even if only one parity error were detected in a frame of data, the frame was categorized as bad.

Depending on the data edit mode selected by the station computer operator, preambles were to be inserted after a designated number of frames were decommutated. Occasionally preambles were not inserted at the proper interval. When this occurred, the SNOMAN was notified and he in turn notified the station to take appropriate action. When the digit *one* appeared in the header, the

Table 24. Mission II telemetry data monitoring summary of the DSN

Description	DSS			Total
	41	61	12	
Total passes	31	30	30	31
Total frames transmitted	32,663	31,772	27,094	91,529
Total good frames received at SFOF	31,317	30,490	26,776	88,583
DSN performance[a], %	95.87	95.96	98.82	96.78
Questionable frames (Project)[b]	151	156	184	491
Bad frames (DSN)[c]	1,164	1,122	99	2,385
Bad and questionable frames	32	8	35	75
Total bad frames[d]	1,347	1,286	315	2,951
Questionable frames, %	0.46	0.49	0.67	0.53
Bad frames, %	3.56	3.53	0.36	2.60
Bad and questionable frames, %	0.09	0.02	0.12	0.08

Adjustments were made for occultation outages and DSS in-lock times.

[a]$\% = \frac{\text{total good frames received at SFOF}}{\text{total frames transmitted}}$.

[b]All frames identified in the header as questionable (i.e., digit one) were categorized as questionable.

[c]All frames with one or more parity violations were considered bad.

[d]Total bad frames = questionable frames + bad frames (DSN) + bad and questionable frames.

Project was charged with questionable frames, meaning that the operation of Project mission-dependent hardware or software was questionable.

The low percentage of data recovered during the initial pass over DSSs 41 and 61 was attributed to the poor teletype communication link caused by predicted propagation interference. The overall performance of the DSN provided the Project with over 95% "error-free" data transmitted in real time. Mission II was the first mission to be analyzed; consequently comparisons cannot be made with previous projects.

Part IV. *Lunar Orbiter III*

I. Introduction

A. Mission III Objectives

The primary aim of Mission III was essentially unchanged from the two prior missions with the exception that Mission III was designed for a confirmation of sites rather than a search for sites. Twelve primary sites were selected by NASA, five from analyses of Mission I photos and five from Mission II photos, of areas that appeared sufficiently smooth to justify additional photography. Two possible sites for *Surveyor* landings in the western Mare Tranquillitatis were selected from earth-based photography.

The secondary aims were (1) to provide precision trajectory data in order to gain more precise information about lunar gravitational harmonics; (2) to obtain micrometeoroid flux and radiation dose measurements of the lunar environment, primarily for spacecraft performance analysis; and (3) to provide a spacecraft in lunar orbit for the exercising and evaluation of the MSFN tracking network and *Apollo* Orbit Determination Program.

B. Mission III Summary

Mission III was launched from Complex 13, Cape Kennedy, at 01:17:01 GMT, February 5, 1967, in a February 3–8 launch opportunity. Despite numerous prelaunch problems, liftoff was successfully accomplished on a flight azimuth of 80.8 deg at the start of the launch window. Preliminary analysis of AFETR metric and telemetry data indicated satisfactory performance by the first- and second-stage vehicles. The *Agena*–spacecraft combination was placed in a parking orbit for approximately 10 min and then injected into a cislunar trajectory. The spacecraft then separated from the *Agena*, automatically completed its deployment sequences, and acquired the sun. A single midcourse maneuver was successfully performed 38 h after launch. After 92.5 h of cislunar flight, the spacecraft was injected into an initial high periselenium (210 km) orbit and tracked for approximately four days (25 orbits) to obtain data for analysis of the lunar gravitational effect. The spacecraft was transferred to a low periselenium (55 km) photographic orbit. Lunar photography began on February 15, 1967 and was successfully completed on February 23.

All requirements placed on the TDS for the support of Mission III were met and, in many areas, were exceeded.

II. Preflight Readiness

A. General

The preflight readiness of the TDS was established by means of DSN Compatibility, Verification, and Readiness Tests, a DSN Readiness Review, and a Near-Earth Readiness Review. The reviews were held approximately 2 wk before launch and were organized to determine the capability of each TDS element to support the mission, to specifically identify and discuss any existing or anticipated problems, and to establish a schedule for their resolution. The results of these reviews were then submitted by the TDS manager to an overall Flight Readiness Review which was conducted by the *Lunar Orbiter* Project at Cape Kennedy.

B. Preflight Tests

1. General. Preflight testing for Mission III proceeded according to the test plan and philosophy described in Part I, Section VI, of this report. These included:

(1) Spacecraft–DSIF Compatibility Tests.

(2) DSIF–Mission Dependent Equipment (MDE) Integration Tests.

(3) Software Integration and Verification Tests.

(4) Near-Earth Phase Tests.

(5) TDS Operational Readiness Tests.

Additional tests were conducted for dual spacecraft operational training at DSS 12, and for certification of DSS 62 as a prime *Lunar Orbiter* station to replace DSS 61. The purpose of the dual spacecraft procedural exercise was to familiarize operations personnel with the procedures and techniques required to fly two or more *Lunar Orbiter* spacecraft concurrently. The DSS 62 Certification Test was basically a DSIF test performed to assure the DSIF and the Project that DSS 62 was properly configured, and that communication between DSS 62 and the spacecraft would not endanger the spacecraft. In the absence of a first-order survey, tests were also conducted to establish the geocentric location of DSS 62 by orbit determination techniques. The procedure included tracking the *Pioneer VII* spacecraft in concert with DSS 12.

2. Spacecraft–DSIF Compatibility Tests. Spacecraft–DSIF Verification Tests were conducted at DSS 71, Cape Kennedy, to establish the compatibility of the spacecraft with the DSIF configuration.

3. DSIF Configuration Verification Tests. Configuration Verification Tests were conducted during the month of January at Deep Space Stations 12, 41, 51, 62, and 71. These tests verified that the participating stations were in the proper functional configuration and ready to support *Lunar Orbiter* Mission III.

4. Near-Earth Phase Tests. Near-Earth Phase Tests were performed in conjunction with the TDS Operational Readiness Tests. A total of three such tests were conducted on January 25, 27, and 28, following the readiness reviews. Problems encountered were limited mainly to transmission difficulties with the Range Instrumentation Ships and a computer program problem on board the RIS *Twin Falls* that prevented the ship from transmitting simulated tracking data to the AFETR RTCS. Tests were conducted with the ships in port; transmission tests were performed after leaving port and were satisfactory. A simulated launch conducted January 31 went smoothly except that the launch vehicle C-band radar beacon power and sensitivity were not within specifications. The problem was traced to physical obstructions such as shrubs and trees between the receiving van and the pad.

5. TDS Operational Readiness Tests. Combined system tests of the AFETR, MSFN, NASCOM, and DSN were conducted satisfactorily on January 25, 27, and 28. End-to-end data flow and operational procedures were tested with simulated data.

C. Near-Earth Readiness Review

The Near-Earth Readiness Review was held at Patrick AFB, Florida on January 16, 1967. The items requiring action and resolution were essentially routine ones of near-earth station configuration, operational procedures, the communications configuration, and range safety. The most significant problem was receipt of the trajectory data from the Project three weeks later than scheduled. This delayed the AFETR coverage plan. The range was unable to commit to the relocation of aircraft and ships for adequate coverage on all launch azimuths. Although all stations and ships were ready to support the Mission III launch opportunity, there was virtually no overlapping coverage of Class I requirements.

D. DSN Readiness Review

The DSN Readiness Review for Mission III was held at JPL on January 13, 1967 in preparation for the Flight Readiness Review to be held at Cape Kennedy on January 17. Support for Mission III was reported as similar to that provided for Mission II. Significant agenda items were these:

(1) Mission III scheduling conflicts were eased by the rescheduling of *Surveyor* C to April 1967.

(2) Local staffing for mission dependent equipment operation at DSS 41 was not possible.

(3) A dual-mission operation plan was required to maintain extended mission support for *Lunar Orbiter II* during the Mission III photographic phase.

(4) Procedures were developed for monitoring tracking data to ensure against a loss similar to the loss of early DSS 51 tracking data experienced during Mission II.

(5) Troubleshooting of both hardware and software in a search for the SFOF 7044-7094 communications error was continuing. Computer down-time caused by the error was approximately 1% (about 3 min out of 8 h).

(6) Certification of DSS 62 as a prime DSN station for *Lunar Orbiter* was progressing on schedule.

(7) The FR 900 tape recorder was to be committed for Missions III, IV, and V. Performance was on a "best efforts" basis for Missions I and II.

(8) The DSIF IMP was determined as the cause of APS failures during Missions I and II. It was decided not to operate the IMP during photo readout for Missions III, IV, and V until the program was modified.

In summary, the DSN confirmed its readiness to support the February launch window.

III. Near-Earth Operations and Performance Summary

A. Countdown Summary

1. Prelaunch countdown. The countdown included two, planned, built-in holds consisting of a 50-min hold at $T-60$ and a 10-min hold at $T-7$ min. The launch window for February 5 was 110 min long, extending from 01:17 to 03:07 GMT.

The countdown was started at 15:17 GMT on February 5. Although no additional hold time was required, several problems were encountered. At 20:00 ($T-256$ min) the Patrick AFB radar was reported not operationally ready (NOR) because of an azimuth drive motor failure. The motor was replaced and the radar was returned to operational status at 23:04 ($T-73$). At 20:30 ($T-227$) the navigation computer on board the RIS *Twin Falls* was reported NOR and remained in the red until the built-in hold at $T-7$. Just before launch ($T-0$) the ship's metric data transmission system was declared NOR because of calibration problems, and was in the red at liftoff. The Bermuda FPQ-6 Radar was placed in the red at 22:30 ($T-107$) owing to a hydraulic system failure. The station was momentarily declared green at 00:58 ($T-9$) but was again red at $T-6\frac{1}{2}$ and remained in the red through launch. The time of first motion was 01:17:01.120 GMT, February 5. The near-earth support station configuration for Mission II is shown in Fig. 51.

Nominal near-earth mark event times versus actual times are shown in Table 25. All differences between actual and nominal times were within tolerance. The marks were reported by voice in real time and were followed later with a confirming report of the precise times of occurrence. Table 26 lists the reporting source and the Greenwich Mean Time of the marks as reported in real time.

2. Launch decision. At $T-0$, conditions for metric coverage appeared marginal. The RIS *Twin Falls*, a prime metric requirement, was not operationally ready, and the Grand Canary radar was not expected to meet Class I metric requirements, because of low elevation look angles. Well aware of these problems, the *Lunar Orbiter* Project management decided to proceed with the launch. The decision was based on (1) the availability of DSS 51 to provide Class I metric data in place of the RIS *Twin Falls*, and (2) the use of the Bermuda FPS-16 Radar as primary for metric data and range safety. The Bermuda FPQ-6 Radar that normally performs these functions was not operationally ready. The Bermuda FPS-16, however, could see the vehicle only on the early launch azimuths, since its view would be blocked by ground structures on later azimuths. Any decision to hold for a later azimuth would cause additional delay while the necessary range safety and metric coverage requirements were redistributed to other AFETR stations. Further, the air conditioning used to cool the spacecraft at the launch pad

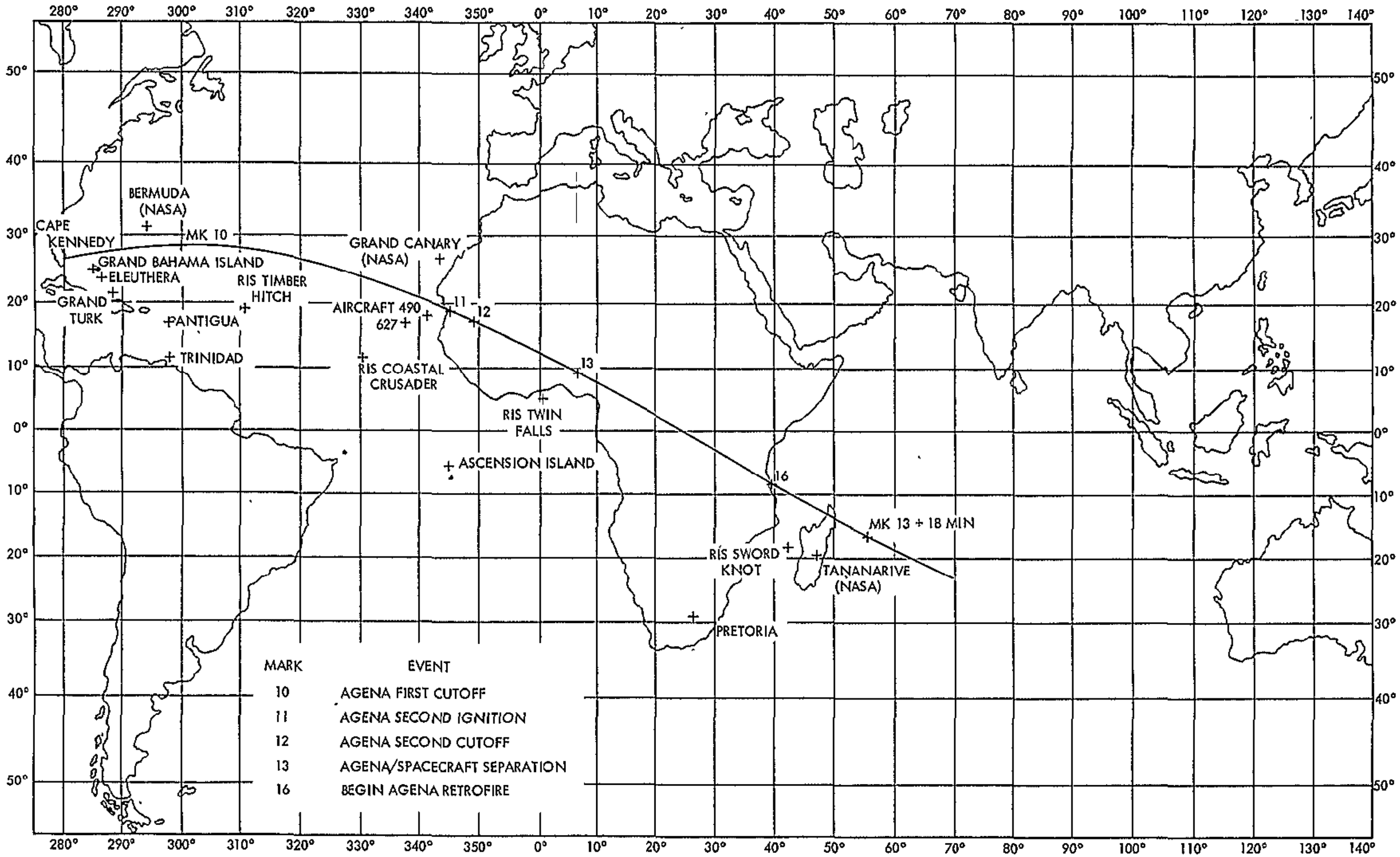

Fig. 51. Mission III near-earth support station locations

Table 25. Mission III nominal mark event time vs actual time

Mark	Event	Time from launch		Report source
		Nominal, s	Actual, s	
1	*Atlas* booster cutoff	129.90	129.71	Tel-4
2	*Atlas* booster engine jettison	132.90	132.58	
3	Start *Agena* secondary timer	268.85	270.56	
4	*Atlas* sustainer cutoff	288.10	288.68	
5	Start *Agena* primary timer	293.70	297.36	
6	*Atlas* vernier cutoff	308.60	309.36	
7	Shroud separation	311.00	311.46	
8	*Atlas/Agena* separation	313.00	313.56	
9	*Agena* first ignition	367.85	371.64	Tel-4
10	*Agena* first cutoff	522.55	527.43	Antigua
11	*Agena* second ignition	1104.00	1105.68	RIS *Coastal Crusader*
12	*Agena* second cutoff	1192.35	1194.38	Grand Canary
13	*Agena*/spacecraft separation	1356.85	1358.55	Aircraft
14	Begin *Agena* yaw	1359.85	1362.08	RIS *Twin Falls*
15	End *Agena* yaw	1419.85	1427.08	RIS *Twin Falls*
16	Begin *Agena* retrofire	1956.85	1958.58	RIS *Twin Falls*
17	End *Agena* retrofire	1974.85	1974.38	RIS *Twin Falls*
	Agena first burn duration	154.70	155.79	
	Agena second burn duration	88.35	88.70	

Table 26. Time of mark events

Mark event	Time, GMT	Report source
First motion	01:17:01.12	Tel-4
1	01:19:10.83	
2	01 19:13.70	
3	01:31:31.68	
4	01:21:49.80	
5	01:21:58.48	
6	01:22:10.48	
7	01:22:12.58	
8	01:22:14.68	
9	01:23:12.76	Tel-4
	01:23:12.90	Bermuda
10	01:25:48.55	Antigua
	01:25:48.70	Bermuda
11	01:35:26.80	RIS *Coastal Crusader*
	01:35:26.77	Aircraft
	01:35:26.70	Grand Canary
12	01:36:55.50	Grand Canary
13	01:39:38.80	RIS *Twin Falls*
	01:39:39.67	Aircraft
14	01:39:43.20	RIS *Twin Falls*
15	01:40:48.20	RIS *Twin Falls*
16	01:49:39.70	RIS *Twin Falls*
	01:49:39.60	Pretoria
	01:49:39.60	RIS *Sword Knot*
	01:48:39.80	Tananarive
17	01:49:55.50	RIS *Twin Falls*
	01:49:55.80	Pretoria
	01:49:58.60	RIS *Sword Knot*

had only limited capability. The total of these factors was judged to favor proceeding with the launch.

B. AFETR Performance

1. C-band radar metric data. Committed metric coverage versus actual coverage is shown in Fig. 52. Despite a number of problems, all Class I metric requirements were met. The most significant problem was the nonoperational status of the RIS *Twin Falls* at launch. At $T + 5\frac{1}{2}$ min the RIS *Twin Falls* metric data transmission system was cleared and good metric data were received at the RTCS. The RTCS processing was faulty, however (see later paragraph B.3).

2. VHF and S-band telemetry data. Expected VHF and S-band telemetry coverage versus actual coverage is shown in Figs. 53, 54, and 55. All Class I VHF telemetry requirements were met. Spacecraft telemetry received through the 98-kHz subcarrier (Channel F) on the *Agena* VHF telemetry link was successfully retransmitted from the receiving AFETR land stations and ships, through Cape Kennedy Tel-2 to DSS 71, and then to the SFOF in Pasadena. Channel F data were selected from the downrange sources and switched to DSS 71 at the times listed in Table 27. Continuous data were received at the Cape with the exception of expected gaps between Bermuda and the RIS *Timber Hitch,* and between the RIS *Timber Hitch* and Grand Canary.

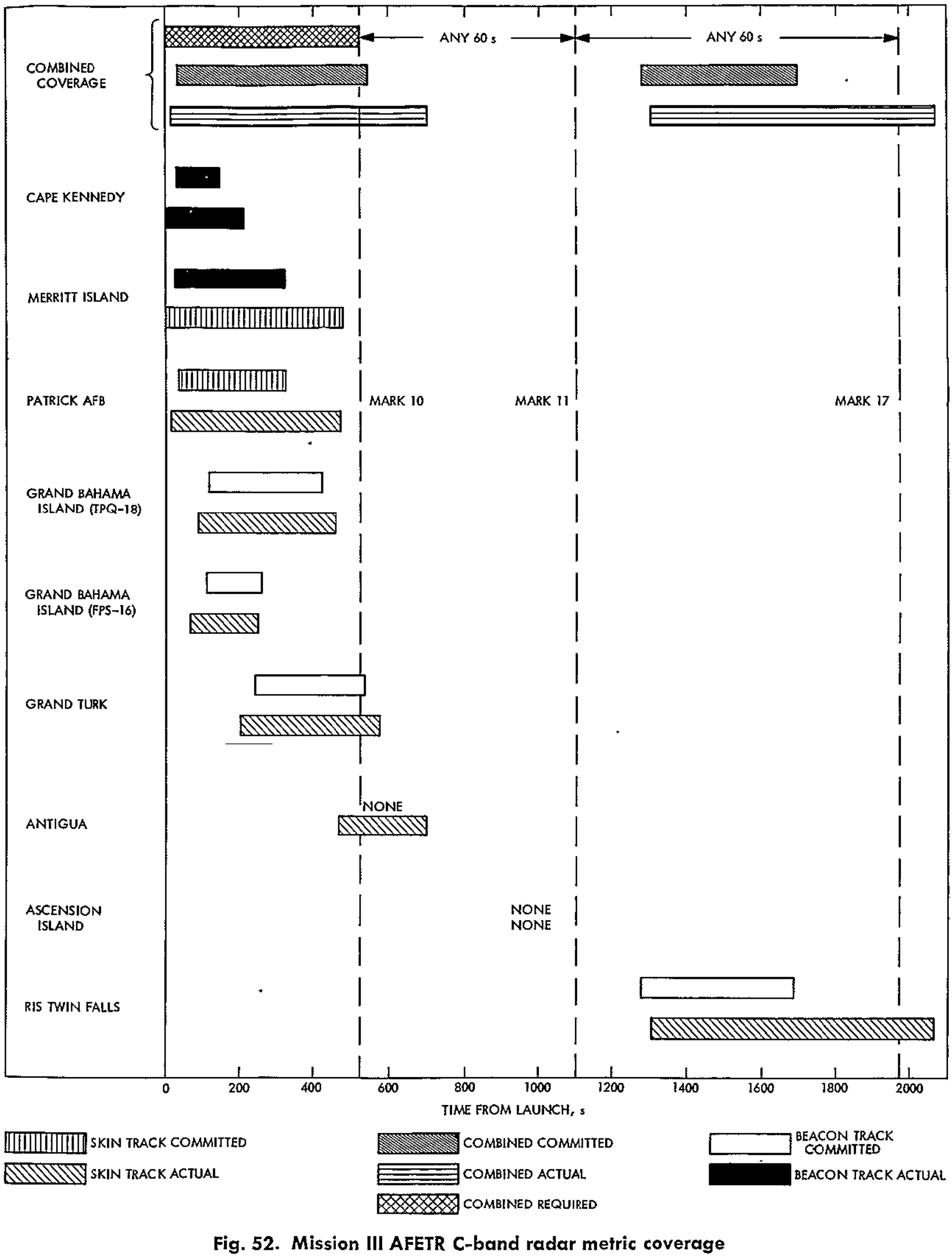

Fig. 52. Mission III AFETR C-band radar metric coverage

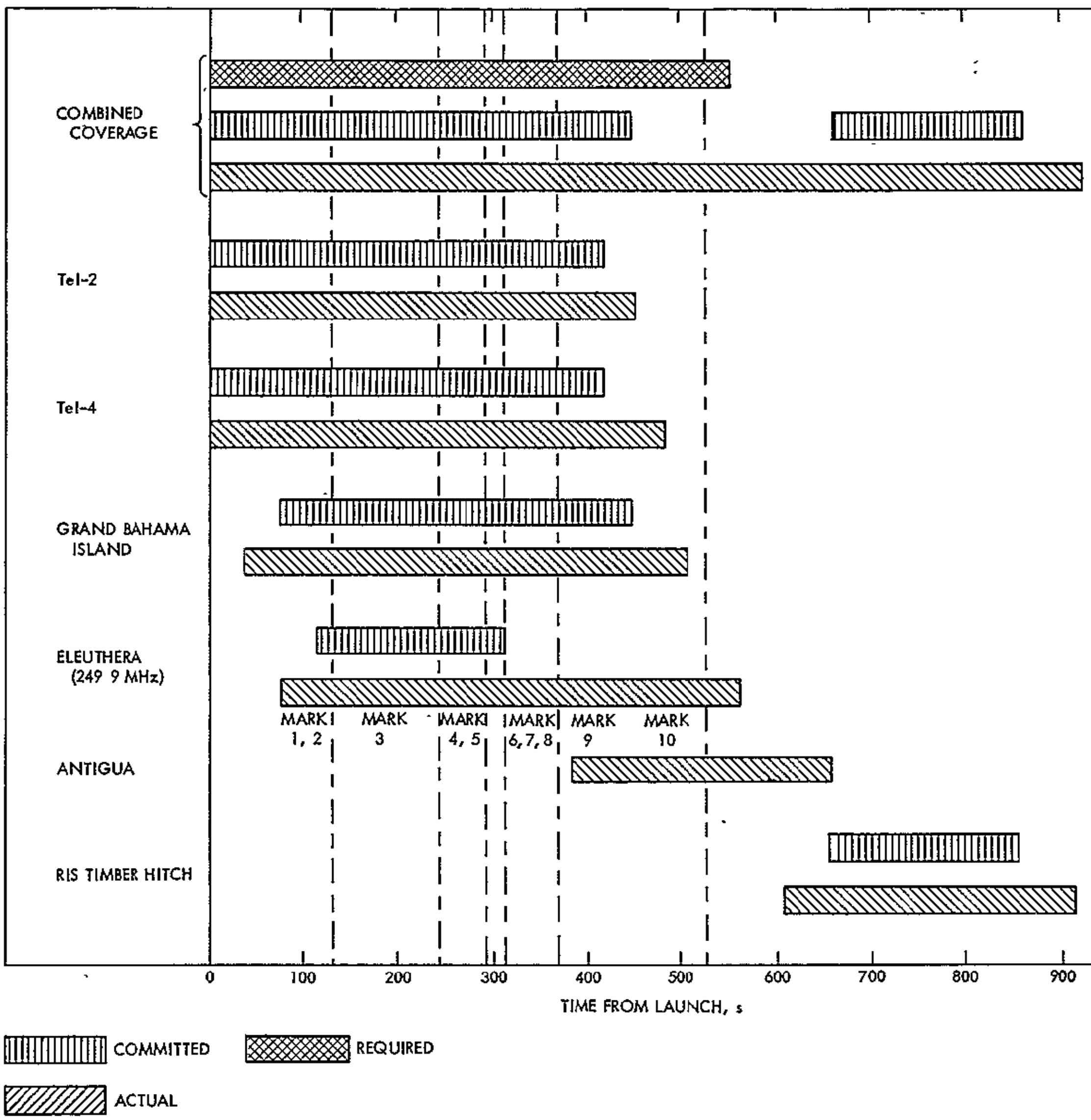

Fig. 53. Mission III AFETR VHF 244.3 MHz telemetry coverage

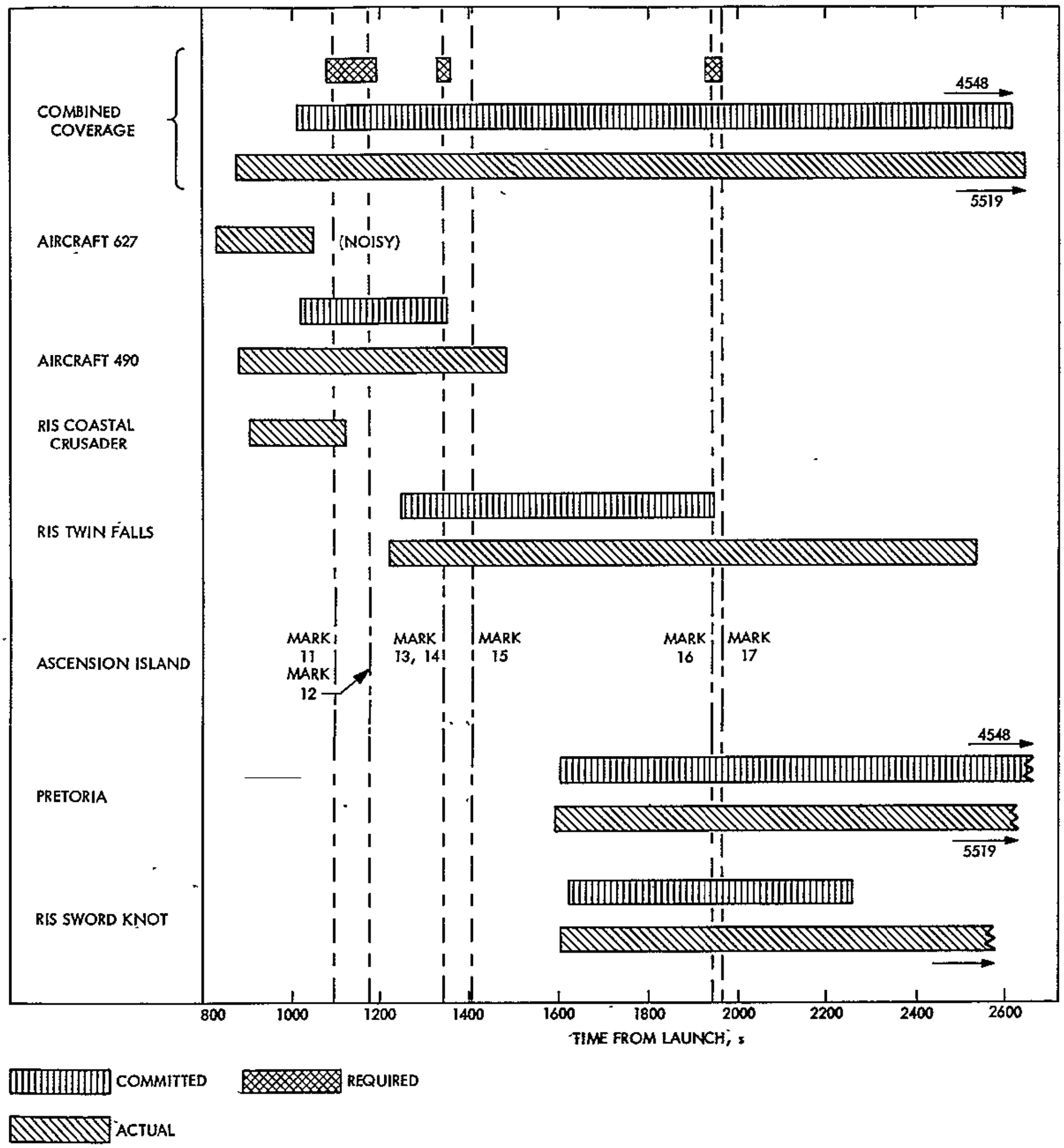

Fig. 54. Mission III AFETR VHF 249.9 MHz telemetry coverage

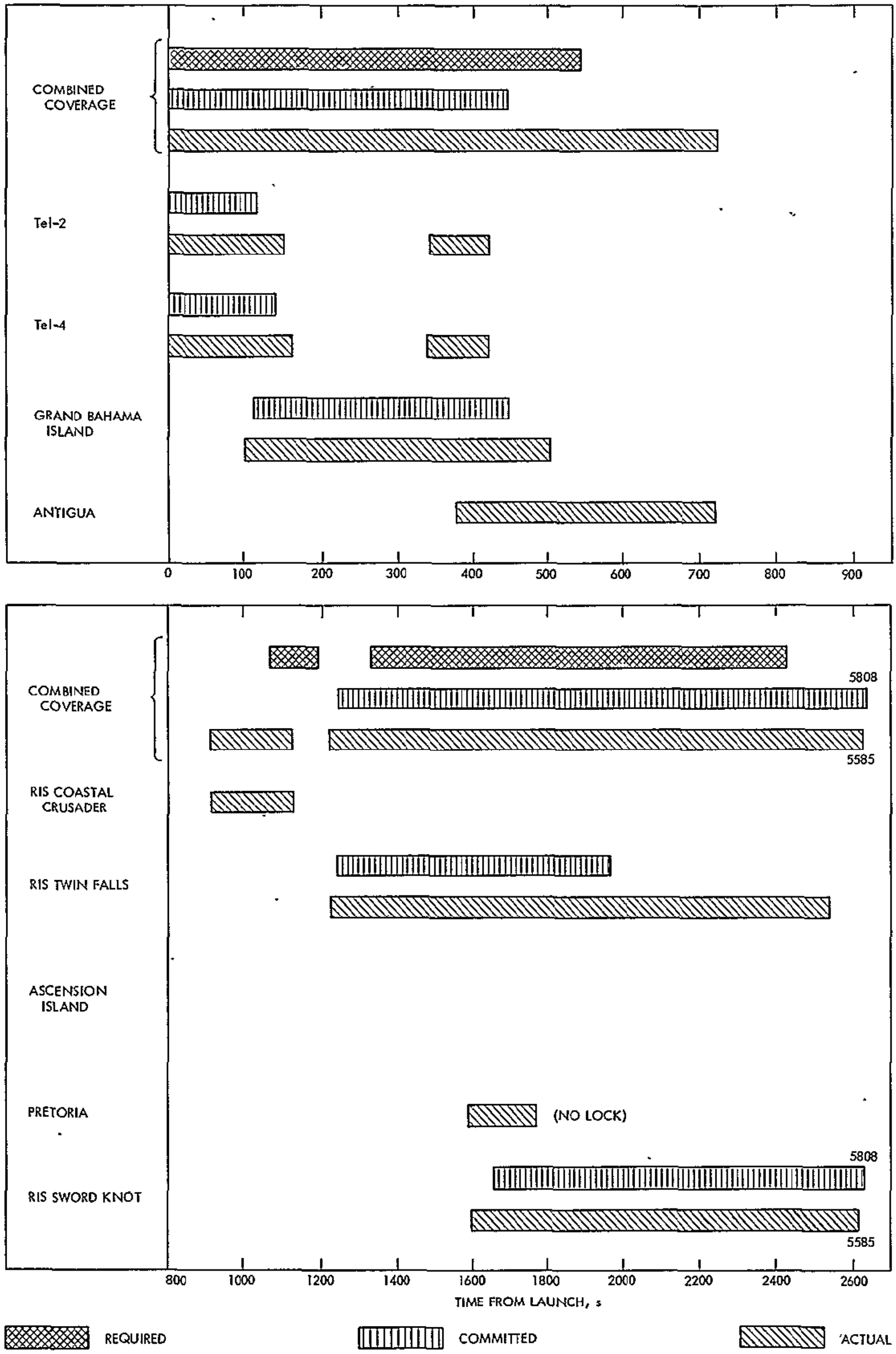

Fig. 55. Mission III AFETR S-band telemetry coverage

Table 27. *Agena* Channel F spacecraft telemetry received at DSS 71 for retransmission to the SFOF

Station	From, GMT	To, GMT	Total frames	Usable frames	Usable, %
Tel-2	Launch	01:19:31	7	7	100.0
Grand Bahama Island	01:10:31	01:24:00	11	10	90.9
Bermuda	01:24:00	01:28:26	12	10	83.3
Grand Canary	01:32:51	01:37:48	12	8	66.7
RIS *Twin Falls*	01:37:48	01:39:40[a]	5	4	80.0
Total			47	39	83.0

[a]Spacecraft separation.

Table 28. AFETR Real-Time Computer System performance

Time from launch, min	Computation
03:55	Liftoff message
13:30	Parking orbit, interrange vector, orbital elements
16:23	DSN predicts to DSSs 41 and 51
16:39	Grand Canary parking orbit look angles
19:14	Nominal transfer orbit, interrange vector, standard orbital parameter message, and orbital elements
27:34	Carnarvon and Tananarive nominal transfer orbit look angles
44:59	Pre-retro interrange vector, orbital elements, standard orbital parameter message
47	DSN predicts to DSSs 41 and 51
49	Carnarvon and Tananarive pre-retro look angles
57	Moon mapping
62	Post-retro interrange vector, orbital elements, standard orbital parameter message (with time bias)
85	Parking orbit standard orbital parameter message
88	Carnarvon data received with correct time
105	Post-retro interrange vector, orbital elements, standard orbital parameter message (with correct time)
114	Moon mapping
125	Pre-retro transfer orbit interrange vector and injection matrix (*I*-matrix)
127	Post-retro *I*-matrix
Deleted	Transfer orbit moon map
148	Final parking orbit standard orbital parameter message, orbital elements
Deleted	Final pre-retro interrange vector, moon map, and *I*-matrix

All S-band telemetry requirements were met, although the signal strength observed at all stations was lower than expected by approximately 6 to 12 dB. (During later analyses, the signal loss was attributed to the collapsing of the aluminum foil thermal blanket around the spacecraft when the launch pad air conditioner was disconnected.) Tel-4 failed to reacquire the signal at $T + 341$ min as planned; this did not affect Class I requirements, however. The RIS *Twin Falls* reported a weak signal; and later had two signal dropouts. The RIS *Sword Knot* also reported a weak S-band signal close to threshold, which resulted in 12 dropouts. Antigua, RIS *Coastal Crusader*, and Pretoria were not committed for a launch azimuth of 80.8 deg but did receive intermittent, low-signal-strength S-band telemetry.

3. RTCS data processing. Computations performed by the RTCS, and the time of the computation, are listed in Table 28. With few exceptions, support was good, and accurate orbits were generated early in the mission. At $L + 8$ min, approximately two minutes of Grand Turk and Bermuda powered-flight radar data was inadvertently deleted during the reloading of a computer. Usable radar data from the RIS *Twin Falls* were received in real time by the 3600 Computer, but transmission to Bldg AO by the 3100 Computer was delayed 8 to 10 min because of a reformatting problem attributed to poor electrical isolation of a 60-wpm teletype machine.

Radar metric data were used to calculate the actual parking orbit, predicted transfer orbit, the actual transfer orbit, and the actual *Agena* post-retro orbit. The actual transfer orbit generated from RIS *Twin Falls* data was used to compute station predicts. A spacecraft orbit was also calculated by using DSS 51 two-way tracking data.

The epoch, the time of computation, the data source, and a qualitative description of the data fit for each of these orbits are listed in Table 29.

Initial lunar encounter predictions (moon mapping) were computed with tracking data from the actual transfer orbit. Table 30 lists the performance of the RTCS and the DSN FPAC Orbit Determination Group in computing some of the initial predictions.

4. Mark event reporting. The reporting of the times of Mark Events 14 and 15 by the RIS *Twin Falls* was about one hour late. The RIS *Twin Falls* was the only

Table 29. Mission III early orbit determination results

Orbit	Epoch, s	Time of computation, s	Data source	Quality
Agena/spacecraft parking orbit	*L* + 546	*L* + 780	Bermuda	Fair
Predicted *Agena*/ spacecraft transfer orbit	*L* + 1193	—	Bermuda	Fair
Actual *Agena*/ spacecraft transfer orbit	*L* + 1194	*L* + 2640	Twin Falls	Fair
Agena post-retro orbit	*L* + 5764	*L* + 8520	Carnarvon	Fair
Actual spacecraft transfer orbit	*L* + 5815	*L* + 7380	DSS 51	Fair

Table 30. Initial lunar encounter predictions

Orbit	B, km	B•TT, km	B•RT, km
Nominal aim point from targeting specification	6,120	5,960	−1,421
RTCS actual *Agena*–spacecraft transfer orbit	7,270	6,687	−2,869
RTCS actual spacecraft transfer orbit	4,840	4,678	−1,262
RTCS *Agena* post-retro orbit	31,100	30,655	−5,141

station to receive these events. Just before their occurrence, the oscillograph recorder which displays the events jammed during a normal speed change. After the pass, the magnetic tape record of the received signal was played back through the receiver system and the mark events were recorded on the oscillograph.

C. MSFN Performance

1. VHF telemetry and C-band metric data. Predicted VHF telemetry and C-band radar beacon tracking coverage versus actual coverage is shown in Figs. 56 and 57. All Class I telemetry and metric data requirements were met. Both Bermuda radars, the FPQ-6 and FPS-16, performed successfully. The FPQ-6 had been in the red at launch owing to hydraulic trouble. The FPQ-6 data were used by the RTCS to compute the actual parking orbit and the predicted transfer orbit. Of the 49 valid data points that were transmitted from Grand Canary Island, 5 points were lost because of poor communications, and 2 points were lost in the reformatting computer. Thirteen consecutive points of valid Grand Canary data representing 78 s of continuous track were transmitted to the RTCS following transfer orbit injection. Although not used to calculate a transfer orbit, the data served to verify the actual transfer orbit as nominal. A 30-min delay occurred before recognition and correction of an improper time tag in the Carnarvon metric data; the corrected data were used by the RTCS to compute an *Agena* post-retro orbit.

2. Data processing and display. The GSFC Data Operations Branch received downrange metric data from Bermuda and the AFETR and, except for Bermuda, who received powered flight data from the AFETR, generated and transmitted nominal pointing data and real-time acquisition messages for MSFN stations. All required computer support was provided.

D. Ground Communications

The performance of NASCOM during the near-earth phase met all support requirements. Communication line problems through Grand Canary Island occurred just before launch and during launch, and caused the loss of about five lines of metric data, which were too noisy to be of any value. An additional line of metric data was lost because of a teletype circuit switching error at the London Communications Center. The velocity meter readout after Mark Event 12 recorded by the Grand Canary station was not received at the Cape in real time because of a break in communications. The readout was confirmed by the Grand Canary station after the pass.

IV. Deep Space Operations and Performance Summary

A. DSN Performance

1. General. Performance by the DSN during *Lunar Orbiter* Mission III was satisfactory, with few operational problems. All commitments were either met or exceeded. Through the training and active photographic mission support periods, the DSN supplied approximately 1234 h of computer support and 972 h of DSIF tracking coverage. The amount of computer use exceeded that provided for Mission II by approximately 20% because of Project requirements for additional orbit determination during picture taking.

2. Configuration control. Many minor changes requested by the Project were effected in the DSN configuration between Missions II and III. All were essentially the result of experience gained during the first two missions. The Project–DSN interface and configuration

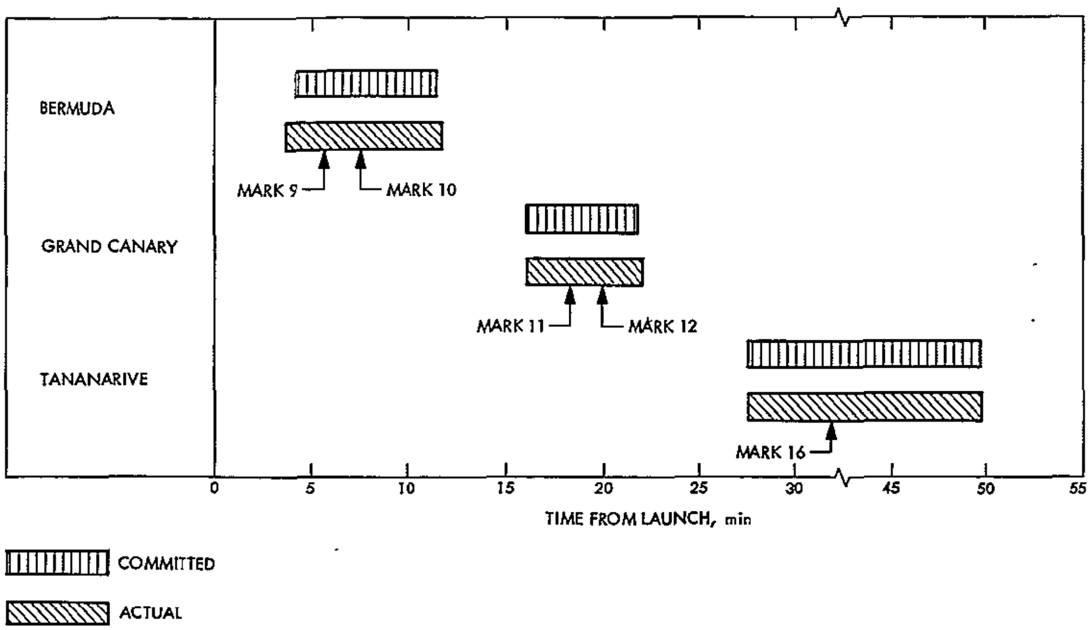

Fig. 56. Mission III MSFN VHF telemetry coverage

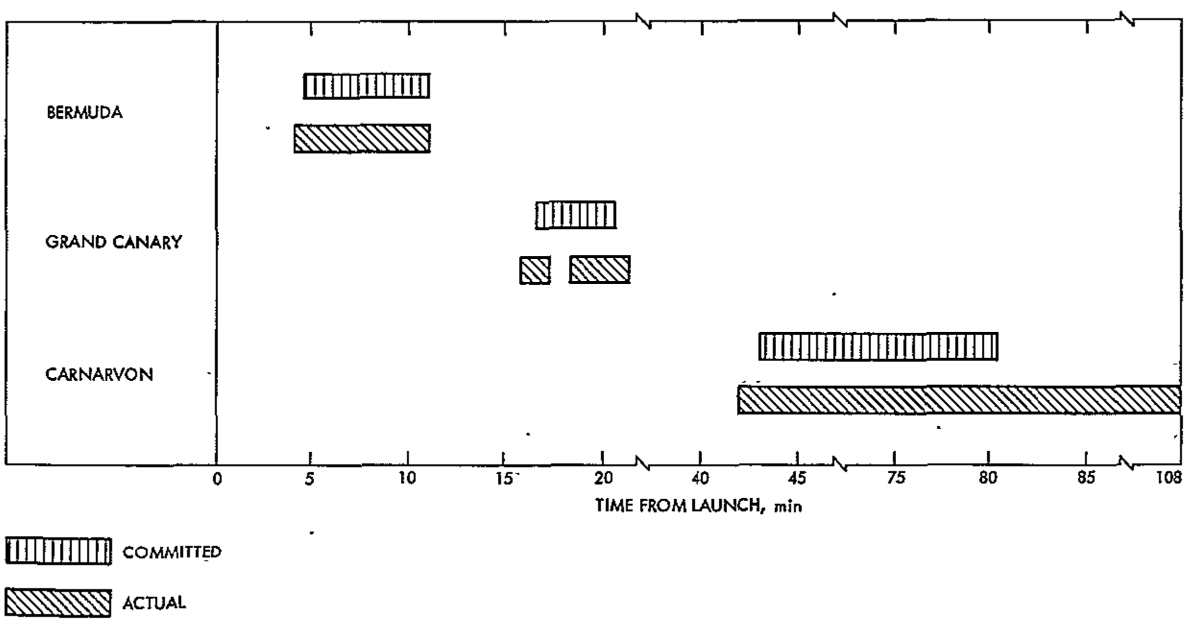

Fig. 57. Mission III MSFN C-band radar metric coverage

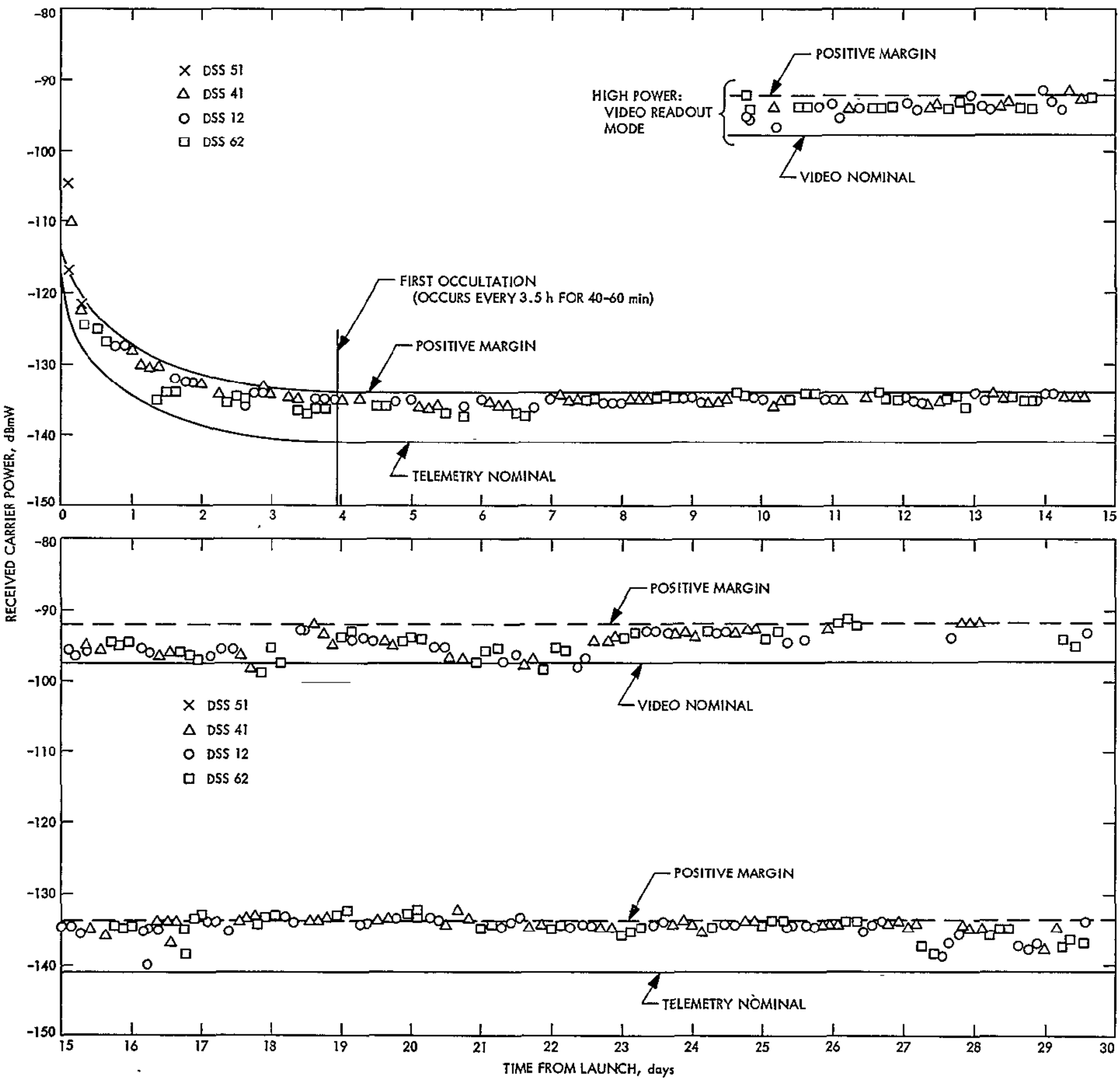

Fig. 58. Mission III received signal strength

control document was able to reflect an accurate configuration for the DSIF, but was not able to keep the SFOF configuration current because of a large number of last-minute changes. The SFOF change control group was consequently used as a clearing house for any building changes affecting the *Lunar Orbiter* Project during Mission III.

3. ***Simulation.*** The use of the Mission II spacecraft as a source for tracking and data added greatly to the realistic exercise of all DSN elements during Mission III training and tests. The SDCC computer system was improved by providing an outbound high-speed data line capability.

4. ***Flight support.*** No major DSN flight support problems occurred during Mission III. To replace DSS 61, DSS 62, Madrid, was articulated into the DSIF configuration. Owing to the excellent cooperation between the DSN and Project elements concerned, the change was accomplished in a relatively short time and without any major problems.

5. ***Scheduling.*** The combined efforts of the Project and DSN scheduling personnel resulted in smooth operation throughout Mission III. Project participation was especially effective. The only scheduling difficulty occurred during the picture-taking phase when the Project required an average of 17 additional computer hours per day.

B. DSIF Performance

1. *Flight summary*

a. Launch and initial acquisition phase. Launch occurred at 01:17:00 GMT, February 5, 1967. For 3 min DSS 71 tracked the spacecraft manually in one-way lock.

Deep Space Station 51 acquired the spacecraft at 01:44:45, was in two-way lock on the main antenna beam at 01:46:30, and was locked to the correct synthesizer frequency at 01:47:14. The acquisition was accomplished by using predicts. Because there was no mission dependent equipment at DSS 51, the spacecraft AGC and static phase error were not available as aids. The uplink frequency for DSS 51 at initial acquisition was within 10 Hz of the predicted VCO acquisition frequency.

b. Transit and lunar phase. At 02:07:34 DSS 41 was in three-way lock; two-way track was transferred to DSS 41 at 02:30:00. At 03:45:00 DSS 41 began ranging on the spacecraft with excellent results. Clock synchronization was performed continually during the transit phase.

After injection into the initial lunar orbit at 21:58:00, February 8, 1967, additional clock synchronization refinements and ranging were performed to further check out the ranging system, and to determine the lunar orbit parameters. Except for minor anomalies the stations functioned exceptionally well. Approximately 11 min of data were lost during the power failure at DSS 62 (see Table 31); a total of 36 min of data was lost during the entire 35-day period.

c. Signal levels. The signal levels received at the prime stations are shown in Fig. 58 and can be seen to vary between 3 and 4 dB above predicted nominal values.

d. Station anomalies. The significant anomalies, their causes, and their effects on the mission are listed in Table 31. All prime stations performed normally and were able to work around such anomalies as did occur. The station maintenance level during Mission III was such that all equipment operated satisfactorily except for the minor malfunctions previously noted. Data outages resulting from equipment malfunctions were minor.

2. ***DSIF operations.*** Overall DSIF operational performance for Mission III was satisfactory. The commitment, based on a 34-day mission, was for 949.0 h of tracking. The DSIF tracked a total of 941.73 h or 99.2% of the commitment. Only one major operational error and a limited number of minor errors occurred during the mission. The total coverage provided during both the photographic and selenodetic phases of the mission is summarized in Table 32.

The operational procedures for Mission III were the same as those for Mission II. Exceptions and problem areas were the following:

(1) Just before the midcourse maneuver took place, the station tuned the exciter VCO to zero the transponder static phase error. This action erased a command previously stored in the spacecraft command decoder. The procedure was later changed to eliminate any requirement for tuning the exciter VCO just before a maneuver.

(2) The revised command procedures contained some minor discrepancies that were corrected during operations.

(3) Real-time changes to photo readout procedures by the Project caused much confusion.

Table 31. Mission III summary of DSIF anomalies

Station	Day, 1967	Time, GMT h:min	Anomaly	Probable cause	Remedy	Effect on mission	Comment
12	037	00:00	Prime rubidium standard unstable	Unknown	Switched to backup	None	Random failure
41	037	18:55	Backup rubidium standard failure	Unknown	———	None	Random failure
62	040	09:25	Wrong transmitter power output reading	Loose meter connector	Used spacecraft AGC level as power monitor	None	Random failure
41	041	22:20	60 MHz signal loss at 50 MHz mixer	Bad cable	Installed bypass cable	None	Random failure Discovered before track
12	044	17:55	Unobtainable 1 and 10-s sample rates in TDH	Bad card	Replaced card	None	Random failure
12	044	18:28	CEC oscillograph recorder failure	Galvanometer failure	Replaced galvanometer	None	Common failure
62	046	16:00	Declination skid clutch failure	Open coil	Replaced	None	Random failure Between tracks
12	046	16:00	TDH Punch 2 producing blanks after 6 digits of declination data	Poor calibration	Switch to TDH Punch 1	None	Common failure
41	048	05:24	Unable to calibrate ranging subsystem	Bad SC-10 card	Replaced card	None	Random failure Discovered before track
62	051	08:41	Tracking frequency printed incorrectly	VCO counter maladjustment	Adjusted VCO counter	None	Common failure
62	052	02:20	Declination drive failure	Servo fuse	Replaced fuse	None (DSS 12 in two-way track)	Random failure
62	052	15·55	Station clock recycled to print hours	Unknown	Reset clock	None	Common failure
62	053	17:54	Intermittent omission of last doppler printout digit	Poor calibration	Recalibrated TDH	None	Common failure
12	057	15:22	FR 900 recorder failure	Capstan motor power supply failure	Replaced cards in power suppy	None (DSS 41 in two-way track)	Random failure
12	058	06:30	Defective exciter VCO tuning control	Worn potentiometer	Used external exciter	None	Random failure
12	058	09:10	LB 154 unit intermittent in least significant digit	Unknown	Replaced unit	None	Random failure

Table 31 (contd)

Station	Day, 1967	Time, GMT h:min	Anomaly	Probable cause	Remedy	Effect on mission	Comment
12	058	09:49	Timing grid line loss on CEC recorder	Fuse	Replaced fuse	None	Common failure
41	058	11:31-23:52	Maser off. Low oil pressure	Oil pump	Replaced pump	None	Common failure
62	059	04:10-04:21	Main power failure	Overload	Reduced power demand to 145 kW and reset	11 min of tracking data lost	Random failure
62	060	08:52	Antenna clutch failure	Unknown	Released from track	None	Random failure
62	061	01:59	FR 900 tape packing problem	Lower hub loose	Stopped and changed tape	1 min video recording lost	Random failure
41	061	15:39-16:04	TDH Punch 1 failure	Unknown	Switched to TDH Punch 2	25 min tracking data lost	Common failure
12	064	11:14	Low paramp gain (19 dB)	Unknown	Return paramp	None; tracked on maser	Common failure
12	064	11:18-11:26	CEC recorder failure	Pick-up roller slipping	Adjusted	None	Common failure
41	065	05:06-05:50	Antenna drive (hour angle) hydraulic failure	Coupling failure	Replaced union, added oil, bled system, returned to service	None (DSS 62 in two-way track)	Random failure
41	068	06:18-06:33	Telemetry data stopped	Possible TCP failure	Re-initialized	None	Replayed data during occultation

Table 32. Total DSIF coverage summary for Mission III photographic and extended mission phases

DSS	Two-way tracking, h	Three-way tracking, h	Total tracking, h	Ranging, h	Time correlation, h
12	414.60	92.09	506.69	70.36	0.62
41	405.13	107.85	512.98	84.03	0.43
42	2.07	2.53	4.61	0.35	0.30
51	12.73	4.33	17.06	0.00	0.00
62	372.41	105.15	477.57	60.72	0.33
71	0.00	0.05	0.05	0.00	0.00
Totals	1206.84	312.00	1518.96	215.46	1.68

3. *Tracking data analysis*

a. Performance summary. The DSIF SDA Group provided round-the-clock support from launch through the end of the photo exposure phase of the mission and on a one-shift-per-day basis until completion of photo readout. The function of the Group was to provide liaison and coordination between the Deep Space Stations where the tracking data originates and the DSN and Project FPAC groups who are the data users. The group activities included tracking data monitoring and data quality assessment for the FPAC Orbit Determination Group, frequency inputs to the Orbit Determination Program, acquisition predicts to the Deep Space Stations, and consultation with DSIF Operations Engineering on the solutions to problems.

The performance of the DSIF TDS during Mission III was excellent. There were no major data outages and the good data averaged better than 90% of all data received. The DSIF continued to take good doppler data through the photo readout phases by using Receiver 2 in AGC mode as was done during Mission II. The quantity of ranging data exceeded each of the previous two missions.

b. Predicts generation. The predicts program performed very satisfactorily; the high degree of timing accuracy was due to improved lunar harmonic coefficients and to the higher periselenium of this orbit. The program predicted the first occultation at DSS 12 within one second of its occurrence. There were no predict outages and the current predict sets were received at the stations on time. The only problem concerning predictions was that available computer time conflicted with some of the view period computational runs requested by the Project.

c. Tracking data handling. Tracking data handling was exceptionally good throughout the DSIF. The special procedures for certifying preambles avoided a repetition of the loss of early tracking data that occurred during Mission II.

d. Tracking data monitoring. Tracking data received at the SFOF was sent to the Goldstone computer facility and processed by the TDM program, which performed flawlessly during Mission III. When received, the data were compared with a set of predicts, which were either internally generated or received from the SFOF, and the residuals were computed. The standard deviation of the last five points was calculated and used to determine an estimate of the data noise. The output was transmitted to the SFOF by teletype, printed in tabular form, and displayed on a 30 × 30 X-Y plotter. During the cislunar phase the residuals showed bias errors of less than 1 Hz and noise errors of less than 0.1 Hz, indicating high-quality data.

In lunar orbit the TDM program used JPL predicts, which were sent to Goldstone from the SFOF. During this time the inaccuracy of the lunar model used in the prediction program was reflected in the residuals, which reached fairly high values (approximately 300 Hz). The residuals remained useful for spotting any deviation from the RF carrier during photo readout; no deviations occurred during Mission III, however. The pseudo-noise estimates remained fairly accurate during the lunar orbit phase and corroborated the consistent quality of the data. The ODP later confirmed these results.

Figures 59 through 61 show the result of SDA monitoring of spacecraft velocity maneuvers. The midcourse plot shows a step in the residuals corresponding to the expected velocity change. The lunar orbit injection plot shows a slight deviation from the expected burn owing to the inadequacies of the predict program burn model. The orbit transfer maneuver was plotted by the TDM against the wrong predicted burn. Because of a last-minute change in the design of the burn, there was insufficient time for transmitting the revised maneuver to the Goldstone computer.

e. Problem areas. A few hardware malfunctions occurred but most of these did not result in any data loss. The notable exceptions were the following:

(1) Station 12 was unable to punch 1-s and 10-s data simultaneously during the orbit transfer maneuver. Only 10-s data were taken but they proved adequate for the maneuver analysis; no data were actually lost.

(2) Eighty-three minutes of data were lost because high winds at DSS 12 necessitated stowing the antenna.

(3) The IMP caused the Antenna Positioning Program to drive the antenna off the spacecraft, dropping the downlink. No valuable data were lost, since the event occurred during a transfer, when the data were unusable for orbit determination.

(4) A few points of data were mislabeled when the spacecraft ID number was not changed from 05 to 08 at the proper time.

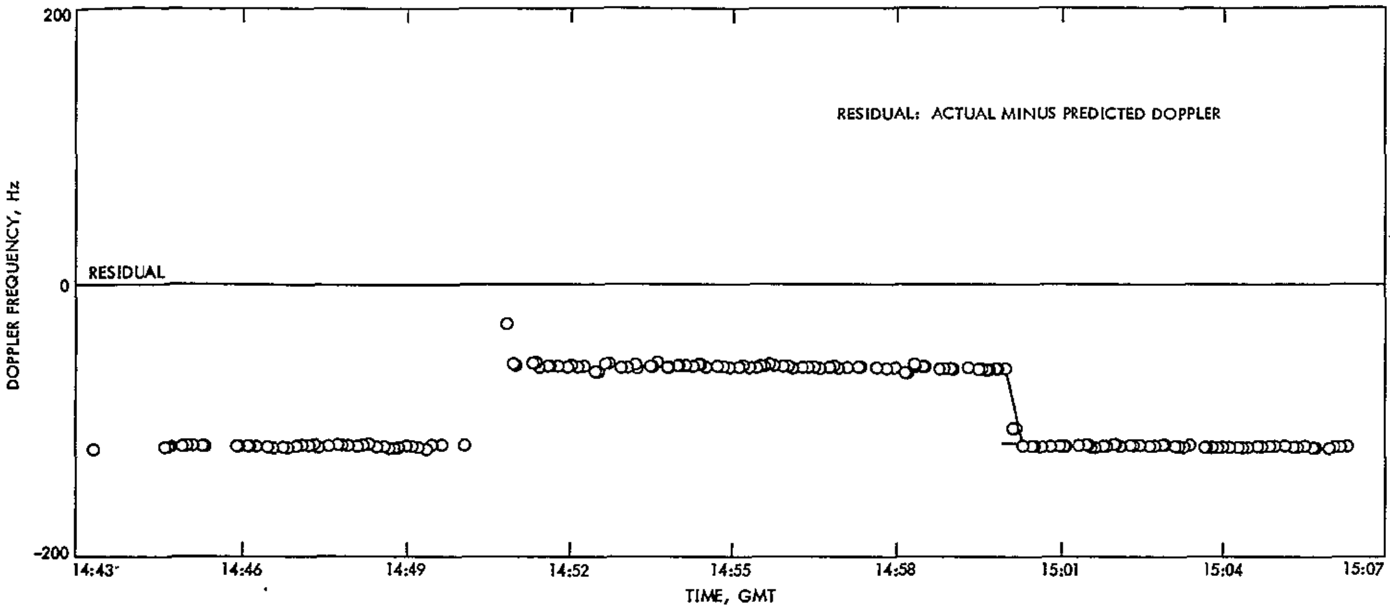

Fig. 59. Mission III midcourse maneuver doppler shift

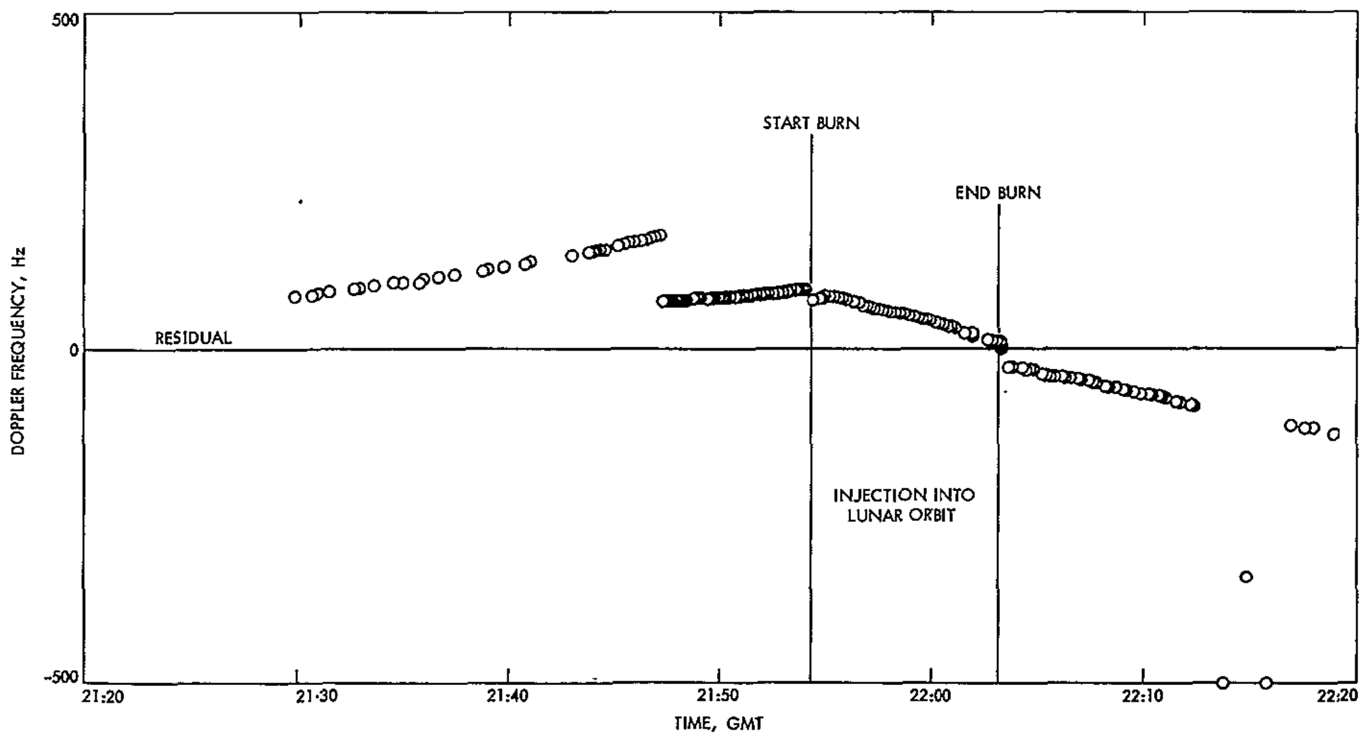

Fig. 60. Mission III orbit injection maneuver doppler shift

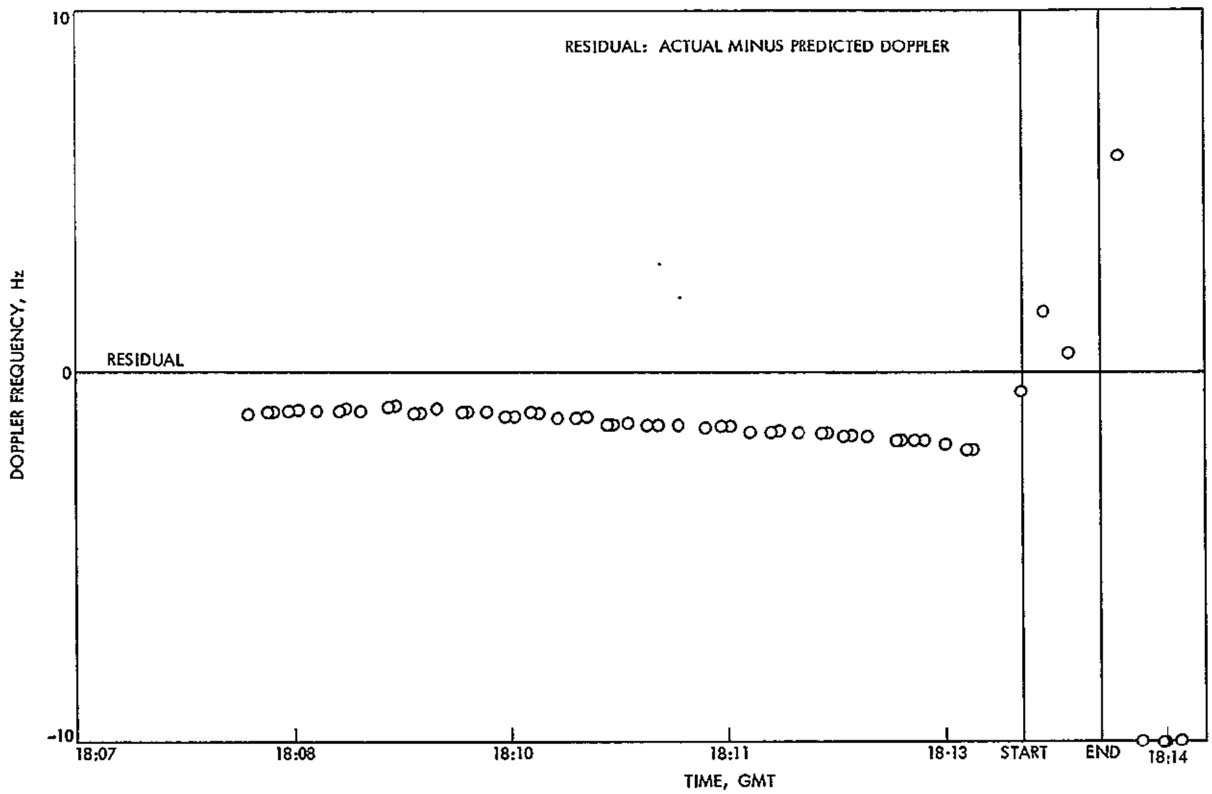

Fig. 61. Mission III transfer maneuver doppler shift

(5) A blown fuse in the DSS 62 servo system caused an unscheduled transfer to DSS 12 and a 5-min data loss.

(6) A power failure delayed a DSS 62 acquisition by 6 min.

(7) Data were lost at DSS 41 when failure of TDH Punch 1 went unnoticed for 35 min before the station switched punches.

4. Ranging and time synchronization

a. Ranging operations. During Mission III an evaluation of the internal station delay portion of the total range delay was made to determine the delay change, if any, that occurred in the station equipment during a pass. Fifty data points were obtained during the mission from a combination of three sites. These were chosen so that the received and transmitted power levels, and station configurations were identical during both the pre- and post-pass calibrations. The period of time between these calibrations varied from 10 to 15 h. In looking at the residual obtained by subtracting the pre-pass calibration figure from the post-pass figure for the 50 points, the mean was found to be about 1.5 range units (1.6 m), with a standard deviation of 3.4 range units (3.5 m). The maximum deviation was about 9 m. These data indicated that a 1½-m delay increase may be expected during the pass. Also, during 50% of the time the change was less than 3 m, less than 5 m during 80%, and less than 9 m during 90%.

b. Station time synchronization. Table 33 shows the results of the preliminary time synchronization measurements with the DSN Ranging Time Synchronization Measurement technique. The tolerance for each point is on the order of 5 μs. Where available, other data have been added to explain discontinuities. Most of the measurement data was obtained during the early phase of the mission, since taking measurements during the photo phase was not possible.

C. GCF/NASCOM Performance

1. Performance summary. The GCF/NASCOM performance during Mission III continued to be consistent and highly reliable. Despite a number of minor problems, high-speed data, teletype, and voice circuits performed reliably during all phases of the mission. High-speed

Table 33. Mission III time synchronization measurements (raw data)

Day, 1967	Time, GMT	Stations		Difference, μs
036	14:45	12	62	782
037	08:05	41	62	1204
037	19:00	DSS 41 clock failures		60 lost
037	15:54	12	62	786
037	20:16	41	12	335
037	21:15	41	12	347
038	08:07	41	62	1142
038	22:40	41	12	358
039	08:05	41	62	1137
039	23:00	41	12	355
040	08:45	41	62	1133
040	16:05	12	62	777
041	00:00	41	12	354
041	09:05	41	62	1128
041	15:15	12	62	773
042	00:10	41	12	353
042	09:15	41	62	1124
042	17:30	12	62	770
043	00:50	41	12	352
043	19:06	12	62	766
044	01:20	41	12	349
044	18:03	12	62	763
045	11:23	41	62	1109
045	19:50	12	62	759
067	21:22	41	12	357
068	14:44	12	62	604
069	15:00	12	62	604
069	22:10	41	12	361
075	03:00	41	12	358

data lines performed with nearly 100% reliability during all tests and mission phases. The DSS 41 circuit, with 99.07%, had the lowest reliability. Outages of short duration to DSSs 41 and 62 during certain critical periods did pose problems with respect to rapid recovery of desired data.

Teletype circuits were also very reliable. Circuits to the three prime stations—DSSs 12, 41, and 62—showed better than 99% reliability. The DSS 51 circuits were the weakest, with 93.9%. Just before the midcourse maneuver, all teletype circuits between London and Madrid were out for 14 min because of a microwave failure. Service was restored 1 min before the start of the command sequence.

Voice circuits performed better than predictions indicated. The least reliable was DSS 71, with approximately 86.22%. The prime stations—DSSs 12, 41, and 62—showed no better than 99% during the mission. On March 7, 1967, *Intelsat* F2 circuits were used to support DSS 41 after a cable failure in the Pacific Ocean between Hawaii and Australia. Results were satisfactory. Commands were sent to the spacecraft over this link by way of DSS 41.

2. *GSFC power failure.* At 03:05 GMT, February 18, a power transformer at GSFC failed, causing damage throughout the power distribution system as well as to numerous data processing systems operating on commercial power. There were numerous, small, secondary fires and considerable smoke. The immediate loss of all commercial power knocked out all communications except for the voice network, which was kept in service with power from a secondary battery supply. All teletype circuits were immediately rerouted through carrier toll test facilities in downtown Washington, D.C., and service was restored within five minutes. *Lunar Orbiter* was provided with six teletype circuits (four operational, two hot standbys). At 04:18 GMT partial power was restored. As a safety factor, GSFC continued to be bypassed until 06:00 GMT, since NASCOM was unsure of the backup power source. The outage had no serious impact on the mission, since it happened during a DSS 12 (Goldstone) pass. Communications between Goldstone and the SFOF in Pasadena are direct and do not rely on GSFC switching.

D. SFOF Performance

1. *Data Processing System.* Software system performance for Mission III was nearly perfect. Much of the system was identical to that used for Mission II, with minor improvements reflecting experience gained during Mission II. Minor errors in some of the user programs were overcome by operational work-around procedures and source deck changes. The TDP program lacked the capability of reprocessing rejected data. The communications inconsistency between the 7044 and the 7094 computers continued to be a problem, but the frequency of the errors was somewhat reduced, occurring at a rate of less than once a day with the total data loss amounting to approximately 1.5 h during the mission.

2. *Data handling and storage.* The handling and storage of station data records was complicated by the lack of identification and time tags on the data. Also, the concurrent tracking of Missions II and III spacecraft created problems in identifying the data when received

at the SFOF. Poor-quality oscillogram records created problems in producing readable microfilm.

3. *Staffing and training.* The DACON (Software Coordinator) position was staffed by Boeing. Training was not required, since all DACON personnel were experienced from Mission II operations. One new system monitor was assigned for Mission III and received valuable training in DACON procedures.

Missions I and II provided excellent training in Project–DSN interface procedures and functional understanding. The improved relationship made it unnecessary to continue the SNOMAN function of the DSN Project Engineer. The elimination of the SNOMAN position necessitated some procedural changes to the new DACON procedures published just prior to Mission III. These were distributed to the DACON personnel and to the system monitors as an addendum pending publication of updated DACON procedures.

4. *SFOF operations.* Operations support from data chiefs, computer operations, equipment operations, data distribution, and key punchers was satisfactory.

E. DSN FPAC Performance

1. *Performance summary.* Tracking data quality reports to the Project were made consistently throughout the active mission (i.e., until the end of the photo readout or the beginning of the extended mission for selenodesy). The quality of data was excellent and met all commitments. Recommendations made at the conclusion of Mission II were carried out effectively.

2. *DSN tracking data quality determination*

a. *Launch phase OD and TDQD performance.* Although the orbit determination process was a DSN responsibility during the first 6 h from launch, both DSN and Project personnel collaborated in generating the first orbit determination. In duplication of Mission I, the near-earth orbits were generated on schedule and showed a nominal injection which was later verified by additional Project orbit determination computations. Some of the AFETR data from Grand Canary Island were used to produce a good orbit as an input for predictions. The angle data from Woomera were used until Goldstone rise, and the consistency of the DSS 62 three-way doppler assured the accuracy of the orbit. Ranging data were also taken during this phase and comparison of position estimates produced from doppler-only calculations showed discrepancies of no more than 25-m with a high-frequency noise of approximately 2 m caused primarily by the single precision calculations in the orbit program. All data used for the midcourse maneuver orbit determination calculation had been evaluated in the TDQD and assessed as good.

b. *Midcourse-to-injection phase.* During the post-midcourse phase, long arc fits (40 h or more of data) showed some inconsistency when ranging data were compared to fits with doppler-only data. Initially, the DSS 62 station location was considered a possible problem; however, when inflight determinations were made, the location estimate indicated only very slight changes from the original orbit determination estimate made with the *Pioneer* tracking data (the *Pioneer* estimate shifted the station some 300 m from the astronomical survey, and agreed with the first-order land survey). Also an incorrect ephemeris scale factor was used, but neither the station locations nor the scale factor cleared up the inconsistency. This bias caused a prediction error for closest approach of approximately 16 s and caused aposelenium in the initial lunar orbit to drop from 3590 km to 3570 km with no appreciable effect on periselenium (negligible effect on mission success).

c. *Lunar orbit phase.* In the lunar orbit phase, all ranging data were consistent with the doppler data and confirmed the doppler-only orbit estimates. A plot of periods of poor tracking geometry was posted so that maximum two-way and three-way doppler coverage would be obtained and good orbits generated. The determination of inclination of the orbit is poor when the line-of-sight lies within the spacecraft orbit plane. This condition recurred approximately every 14 days and simultaneous view during this period was important for good photographic evaluation. Although the amplitude of systematic biases was greater on this mission than on Missions I and II, the fact that the inclination was larger is reasonably explained: when the gravity field is considered, perturbations should be larger for bigger inclinations (i.e., perturbations appear to be a function of latitude).

3. *Problems, comments, and recommendations*

a. *Scheduling.* The procedure begun during Mission II to not specifically schedule TDQD computer time but request it only when an important question arose regarding data quality continued to work very well.

b. *Software.* No data were lost during critical periods. A 6-h data loss occurred when a master file in the editing program malfunctioned; updating became a problem until the file could be remade.

c. Data accuracies and coverage. Data accuracy was approximately 0.01 Hz for a 1-min, continuous-counted doppler sample when not in the photo readout phase, and approximately equal to 0.05 Hz when in the readout phase. The noise level of the ranging data taken near the earth was approximately 2 m (standard deviation) and approximately 10 m at the moon. Data coverage was excellent.

F. DSN Monitor System Performance

1. Performance summary. Monitor operations of the DSN were limited to an 18-day period from February 5 through February 23, when construction and development activities in the Monitor Area prevented further support. Activities were limited to the monitoring and validation of tracking and telemetry data received by teletype. Monitoring and validation of telemetry received by high-speed data lines was originally planned but could not be performed because, through a scheduling oversight, a high-speed data output device was not installed in the Monitor Area.

The following general functions for monitoring tracking and telemetry data were performed by the DSN Monitor Team:

(1) Monitoring of all incoming tracking and telemetry data received by teletype page printer.

(2) Ascertaining that tracking and telemetry data were received in proper format.

(3) Logging information pertinent to the tracking and telemetry data received.

2. Tracking data validation. Tracking data validation consisted of continuous monitoring of incoming data for (1) correct preambles (data identification codes) inserted at the appropriate times, and (2) proper AFETR and DSIF formats. Information such as total data points received data condition codes, anomalies, etc. were logged. Reperforators and IBM 047 tape-to-card punches were used to provide a backup tracking data source. No backup data were required for the launch phase nor were any anomalies detected on the tapes. The Project did request IBM cards for five Mission II passes and five Mission III passes.

3. Telemetry data validation. All telemetry data received by teletype was monitored for the following:

(1) Insertion of correct preambles at appropriate times.

(2) Proper headers.

(3) Proper number of blocks (lines) per Telemetry and Command Processor (TCP) edit mode.

(4) Proper number of characters per block.

(5) Proper frame sync.

(6) Proper Δt between frames.

A bad frame or block was defined as one that violated one or more of the above criteria. All anomalies were logged and categorized as either a DSN or a Flight Project responsibility. The total number of frames and the total number of blocks containing anomalies were tabulated and the results of these tabulations, together with their corresponding percentages, are summarized in Table 34.

During station overlap, the selection of data to be monitored was arbitrary because only two modified teletype page printers were available in the DSN monitor area. However, data were usually selected from the prime (two-way) station.

4. Conclusion

a. Tracking data. Primary losses of data were due to communication failures that injected extra characters into the data stream or caused garbling. During normal transmissions, bad data condition codes caused most of the unusable samples. Tracking data results are summarized in Table 35.

b. Telemetry data. Real-time recovery percentage of telemetry data transmitted by teletype closely paralleled that of Mission II. Most anomalies were attributed to sporadic garbles in the data stream introduced by transmission errors. However, a more precise measurement of good data was obtained for Mission III by tabulating errors on a block basis as well as on a frame basis. The statistics from this method show an overall recovery increase of about 2% over Mission II.

Table 34. Mission III telemetry data monitoring summary of the DSN

Description	Station				Total
	71	41	62	12	
Total passes	196	1,934	18	18	56
Total frames monitored	3.20	1.96	17,366	19,455	55,363
Total good frames received at SFOF	17.35	93.64	16,482	19,323	53,577
Good frames received[a], %	82.65	6.05	94.91	99.32	96.43
Total blocks monitored	0	0.31	95,973	106,314	306,870
Total good blocks received at SFOF	1	19	93,449	105,773	301,725
Good blocks received[b], %	1,169	17,373	97.3	99.49	98.32
Total bad frames[c]	1,132	16,640	894	132	1,796
Bad frames[d], %	96.83	95.78	5.15	0.68	3.24
Bad frames attributed to DSN, %	6,126	98,457	97.76	67.42	93.76
Bad frames attributed to Project, %	5,930	96,573	2.13	32.58	6.13
Bad frames attributed to both, %	96.80	98.0	0.11	0	0.11
Total bad blocks	37	733	2,523	541	5,194
Bad blocks[e], %	3.17	4.22	2.63	0.51	1.69
Bad blocks attributed to DSN, %	27.03	97.00	95.28	55.27	87.56
Bad blocks attributed to Project, %	72.9	2.87	4.52	44.73	12.23
Bad blocks attributed to both, %	0	0.13	0.20	0	0.21

[a] $\% = \frac{\text{total good frames received at SFOF}}{\text{total frames monitored}}$.

[b] $\% = \frac{\text{total good blocks received at SFOF}}{\text{total blocks monitored}}$.

[c] Total bad frames = total frames monitored − total good frames received at SFOF

[d] $\% = \frac{\text{total bad frames}}{\text{total frames monitored}}$.

[e] $\% = \frac{\text{total bad blocks}}{\text{total blocks monitored}}$.

Table 35. Summary of tracking data monitoring

Description	Data source					Total
	AFETR	DSS 51	DSS 41	DSS 62	DSS 12	
Total data samples, s	525	679	11,527	12,163	11,563	36,457
Total good data, s	503	570	10,979	11,046	10,866	33,960
Total bad data, s	15	95	463	763	653	1,983
Total garbled samples, s	7	14	85	354	44	504
Usable data, %	95.80	83.94	95.24	90.82	93.97	93.15
Total bad data, %	2.85	13.99	4.02	6.27	5.65	5.44
Total garbled data, %	1.33	2.06	0.74	2.91	0.38	1.38

Part V. *Lunar Orbiter IV*

I. Introduction

A. Mission IV Objectives

The primary objective for Mission IV was "to perform a broad systematic photographic survey of lunar surface features . . . to serve as a basis for selecting sites for more detailed scientific study by subsequent orbital and landing missions." The secondary objectives were (1) to provide precision trajectory data for gaining more precise information about lunar gravitational harmonics; (2) to obtain micrometeoroid flux and radiation dose measurements in the lunar environment for spacecraft performance analysis; and (3) to provide a spacecraft for tracking by the MSFN stations in order to exercise and evaluate MSFN performance and the *Apollo* Orbit Determination Program.

B. Mission IV Summary

Mission IV was launched from Complex 13 at Cape Kennedy on schedule midway through the launch window at 22:25:00 GMT, May 4, 1967, on a flight azimuth of 100.8 deg. Preliminary analysis of AFETR metric and telemetry data indicated good performance by the first and second stage vehicles. The *Agena*–spacecraft combination was placed in a 100-mile-altitude parking orbit for approximately 10 min and then injected into the cislunar trajectory. The spacecraft then separated from the *Agena*, automatically completed its deployment sequences, and acquired the sun. Acquisition of Canopus was delayed approximately 2 h due to the presence of reflections in the Canopus sensor during the first attempt.

A relatively large midcourse velocity correction (60.85 m/s) was performed 18 h and 20 min after launch. The correction was required to compensate for minor standard trajectory variations from the ideal. These standard trajectories had been completed prior for the definition of the Mission IV photographic mapping mission.

After 88 h and 44 min of cislunar flight, the spacecraft was injected into a high, near-polar lunar orbit with a periselenium of 2,706 km. This orbit was used to conduct the photographic mapping mission. Photography began on May 11, 1967. Some camera problems were encountered which required operational sequence changes. Included in these changes was selective photo readout, to eliminate the readout of blank frames. Final readout was completed on June 1, 1967.

All requirements placed on the TDS for support of Mission IV were met, and in some areas, exceeded.

II. Preflight Readiness

A. General

The preflight readiness of the TDS was established by means of DSN Compatibility, Verification, and Readiness Tests, a DSN Readiness Review, and a Near-Earth Readiness Review. The reviews were held approximately 2 wk prior to launch and were organized to determine the capability of each TDS element to support the mission. Existing and anticipated problems were discussed and a time schedule for their resolution was established. The results of these reviews were then submitted by the TDS Manager to an overall Flight Readiness Review which was conducted by the *Lunar Orbiter* Project at Cape Kennedy.

B. Preflight Tests

Preflight testing for Mission IV proceeded in accordance with the test plan and philosophy described in Part I, Section VI, of this report. These tests included:

(1) Spacecraft–DSIF Compatibility Tests.

(2) DSIF–MDE Integration Tests.

(3) Software Integration and Verification Tests.

(4) Near-Earth Phase Tests.

(5) TDS Operational Readiness Tests.

1. *Spacecraft–DSIF Compatibility Tests.* Spacecraft–DSIF Verification Tests were conducted at DSS 71, Cape Kennedy, to establish the compatibility of the spacecraft (Serial No. 7) with the DSIF configuration.

2. *DSIF Configuration Verification Tests.* Configuration Verification Tests were conducted during the month of April at DSIF stations 12, 41, 51, 62 and 71. These tests verified that the participating stations were in the proper functional configuration and ready to support the mission. DSS 51 was unable to perform all tests because of commitments to the *Surveyor* Program. *Lunar Orbiter* MDE was not at DSS 51; consequently, tests performed in March 1967, to demonstrate support for *Surveyor*, were accepted as confirming capability to support the *Lunar Orbiter* Mission.

3. *Near-Earth Phase Tests.* Near-earth phase testing was performed in conjunction with the two TDS Operational Readiness Tests (ORT). Problems were encountered with computer programs used for simulation, causing inverted telemetry data to be transmitted from Tel-2, Cape Kennedy, to DSS 71. The source of the inverted telemetry problem was an incorrectly positioned switch at DSS 71.

On April 20, the rate gyro for the S-band antenna on board the RIS *Twin Falls* failed, causing the ship's S-band system to be declared NOR. Attempts to locate a spare gyro were unsuccessful. A plan to transfer a spare gyro from the RIS *Sword Knot* was also discarded. The problem was partially solved by adjusting the RIS *Sword Knot's* down range positions to minimize the gap in Class I S-band telemetry caused by the RIS *Twin Falls* failure.

On May 2, the Grand Turk radar reported a defective elevation encoder and was declared NOR. There was insufficient time to ship and install a new encoder before launch. Station personnel worked on the problem and were able to get the defective encoder to operate sufficiently to support the launch.

4. *TDS Operational Readiness Tests.* Combined system tests of the AFETR, MSFN, NASCOM, and DSN were conducted satisfactorily on April 26 and May 1, 1967. End-to-end data flow and operational procedures from $L - 6$ h to $L + 6$ h were tested using simulated data. The AFETR, MSFN and DSN were green continuously throughout both tests except for periodic communications failures and the previously noted telemetry equipment problems.

C. DSN Readiness Review

The DSN readiness review for Mission IV was held at JPL on April 10, 1967, in preparation for the Flight Readiness Review to be held at Cape Kennedy on April 13. DSN support for Mission IV was to be essentially the same as for Mission III. Significant items on the agenda were:

(1) *Apollo* GOSS Navigation Qualification: MSFN two-way tracking of one of the *Lunar Orbiter* spacecraft was scheduled to begin at the conclusion of the photo mission.

(2) Analysis of the requirements for multiple spacecraft tracking indicated a need for additional DSIF tracking time during the photographic mission in order to keep *Lunar Orbiter II* and *III* alive.

(3) A number of personnel changes had taken place in the DSN FPAC group but no additional training was anticipated.

(4) S-band preflight nominal predictions for DSS 51 had not yet been supplied to the DSN by the Project.

(5) The maser at DSS 62 was expected to be operational by May 1. The station's backup 60 Hz power generator was also inoperative; a replacement generator was expected to be operating by May 1.

(6) The Project indicated that a second photo readout might be required after the priority readout; additional FR 900 recording tape would be required at the DSIF stations.

(7) The 7044-7094 communications error problem had not yet been clearly identified or the cause located. Tests were run without significant results. The frequency of the error was decreasing; total computer down-time during Mission III was 1.5 h.

(8) The Mission Control area in the SFOF had been modified between missions to improve closed circuit television coverage in the area; additional communications facilities were provided.

(9) The DSN Data Processing Engineer position had not yet been filled. This appointment was considered critical.

(10) The GCF teletype switching system used during Missions I, II, and III was also to be used for Mission IV. A new CP recently installed at JPL would not be utilized since there was insufficient time to check out *Lunar Orbiter* teletype communications via the CP.

With respect for the current status, the DSN was reported ready to support Mission IV and recommended proceeding with the launch.

III. Near-Earth Operations and Performance Summary

A. Countdown and Flight Analysis Summary

The countdown was started at 12:25:00 GMT on May 4. Although several problems occurred during the minus count, no additional hold time was required. At 18:41:00 GMT the Pretoria radar was declared NOR because of a digital ranging equipment problem. With the exception of the RIS *Twin Falls* S-band antenna, all major problems were solved prior to liftoff; first motion was recorded at 22:25:00 GMT. The near-earth support station configuration is shown in Fig. 62.

Nominal versus actual near-earth mark event times are shown in Table 36. In all cases the difference between actual and nominal times was within tolerance. The marks were reported by voice in real time and followed later with a confirming report of the precise times of occurrence.

B. AFETR Performance

1. C-band metric data. Committed versus actual metric coverage is shown in Figs. 63 and 64. All Class I metric requirements were met. The Pretoria radar digital recorder power supply failed after 3 min of track and all on-station recorded data were lost after that time. The data transmitted in real time were not affected and the Class I requirement was met prior to the failure. The problem was traced to a malfunctioning vacuum tube in the recorder. The tube was replaced after the pass.

2. VHF and S-band telemetry data. Committed versus actual VHF and S-band telemetry coverage is shown in Figs. 65, 66, and 67. All telemetry requirements were met by combinations of the committed land stations and range instrumentation ships. Minor data dropouts occurred at Antigua, Pretoria, and on the RIS *Coastal Crusader.* Spacecraft telemetry received via the 98 kHz subcarrier (Channel F) on the *Agena* 244.3 MHz VHF telemetry link was successfully retransmitted from receiving AFETR stations through Cape Kennedy Tel-2 to DSS 71 and then to the SFOF in Pasadena. Channel F data were

Table 36. Mission IV nominal vs actual mark event time

Mark	Event	Time from launch	
		Nominal, s	Actual, s
	Liftoff (2-in. motion)	0.0	22:25:00.571 GMT
1	*Atlas* BECO	128.9	128.2
4	*Atlas* SECO	288.2	289.4
5	Start *Agena* primary sequence timer	292.2	292.1
6	*Atlas* VECO	308.3	310.1
7	Nose shroud ejection	310.5	312.5
8	*Atlas–Agena* separation	388.2	338.1
9	*Agena* first-burn ignition	366.4	366.3
10	*Agena* first-burn cutoff	518.7	518.2
11	*Agena* second-burn ignition		1761.24
12	*Agena* second-burn cutoff		1848.66
13	*Agena* spacecraft separation		2013.03
14	Begin *Agena* yaw		2016.1
15	Stop *Agena* yaw		2075.2
16	Begin *Agena* retrofire		2613.6

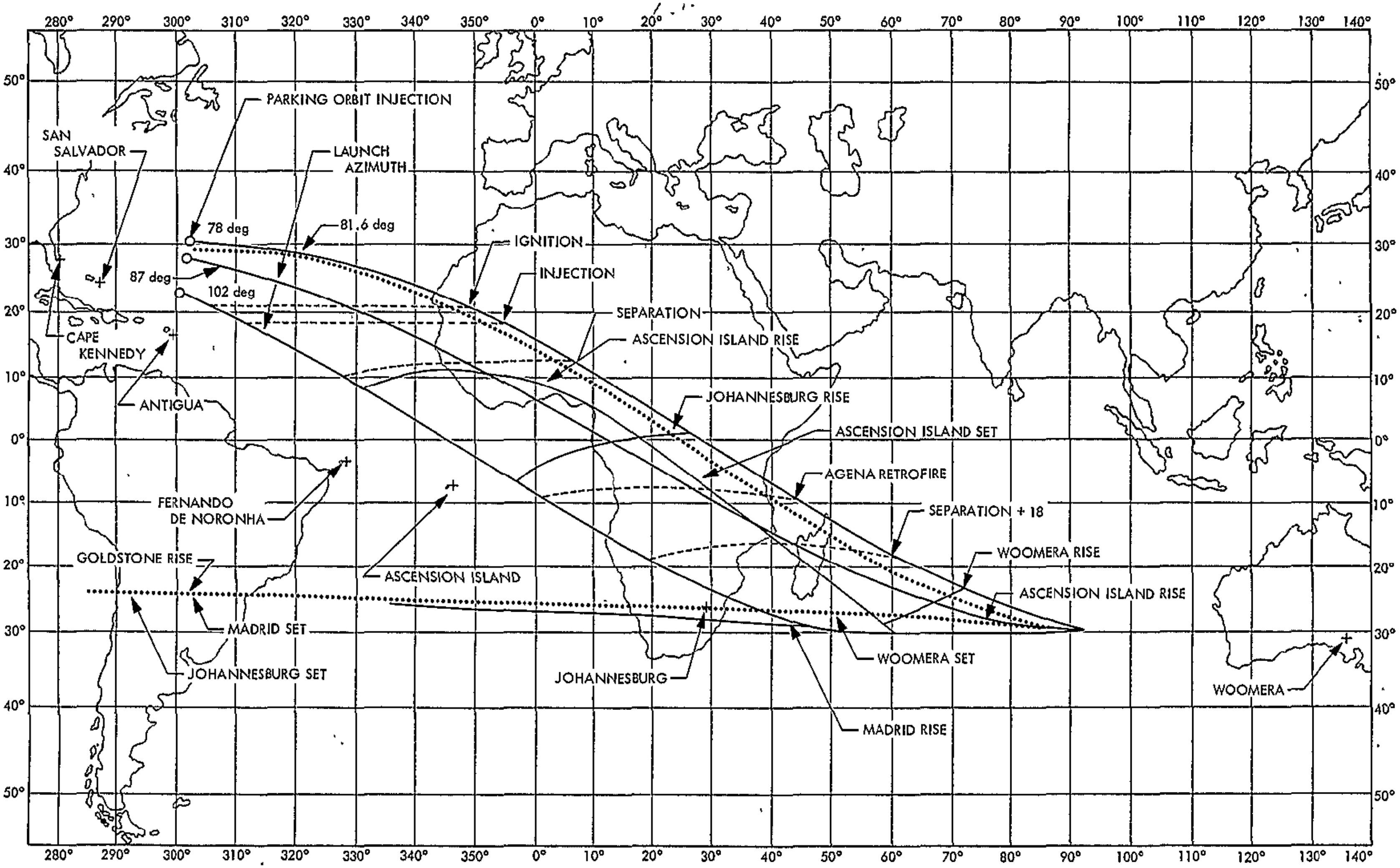

Fig. 62. Mission IV near-earth support station location

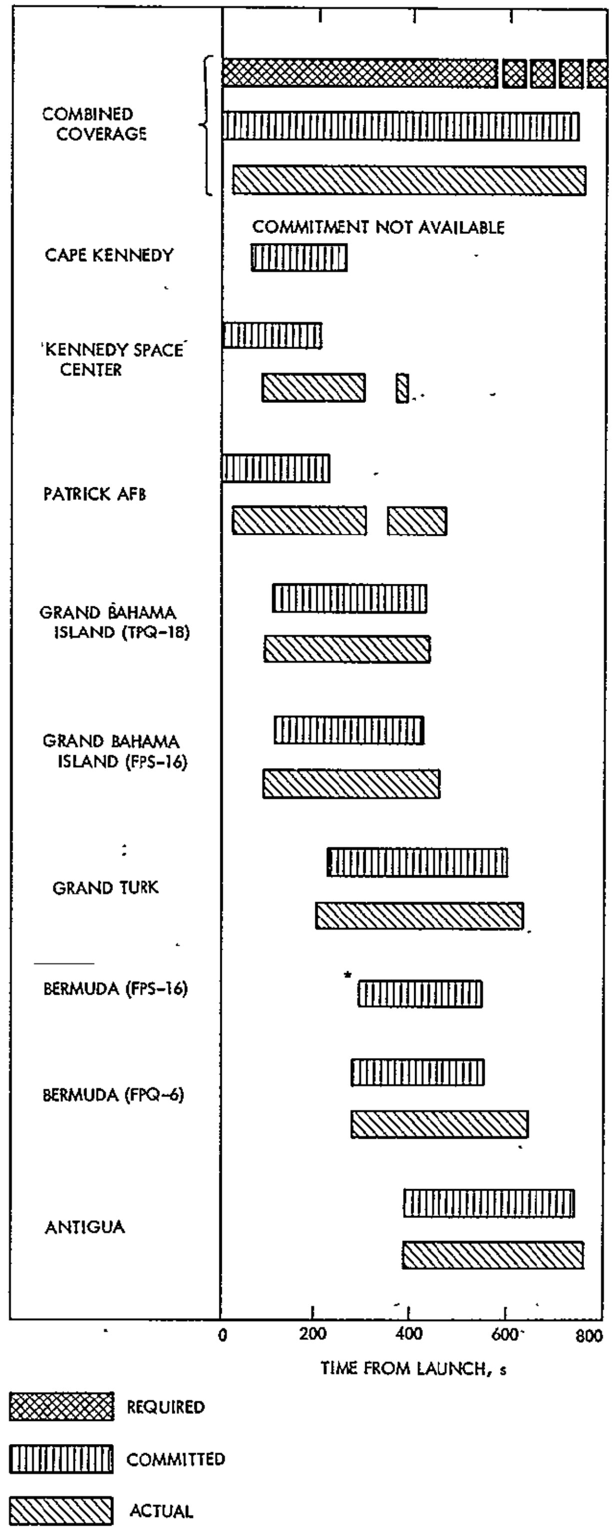

Fig. 63. Mission IV AFETR and MSFN radar metric coverage, launch through Antigua

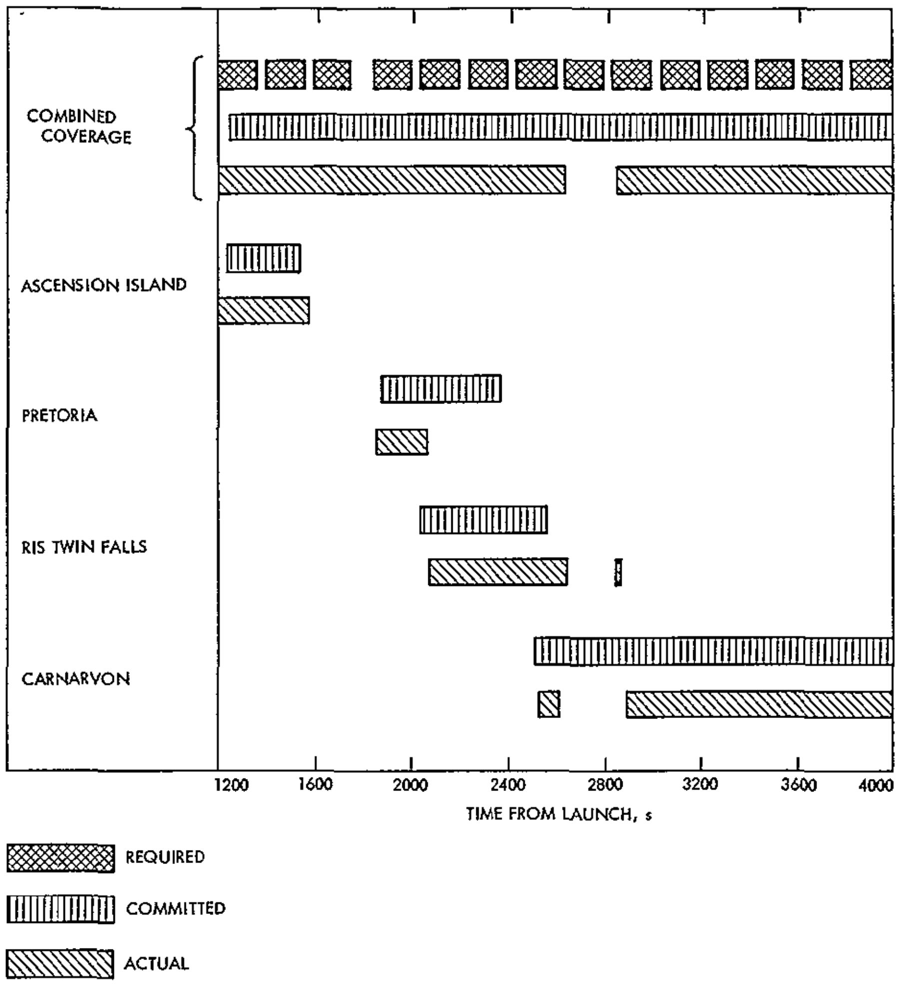

Fig. 64. Mission IV AFETR and MSFN radar metric coverage, Ascension Island through Carnarvon

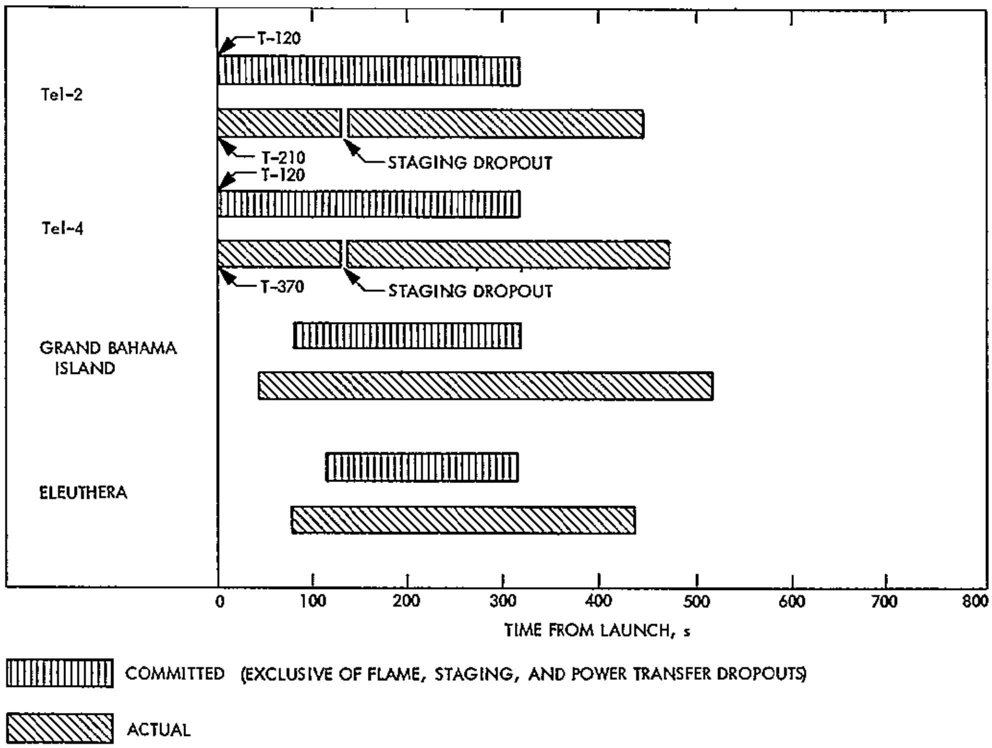

Fig. 65. Mission IV AFETR VHF 249.9 MHz telemetry coverage

selected and switched to DSS 71 from the various downrange stations at the times listed in Table 37.

3. ***RTCS data processing.*** Computations performed by the RTCS met all of the DSN tracking and trajectory data requirements satisfactorily. The handover of processing responsibility to the SFOF at the end of the near-earth phase ($L+6$ h) was accomplished smoothly.

C. MSFN Performance

1. ***VHF telemetry and C-band metric data.*** Predicted versus actual VHF telemetry and C-band radar metric data coverage in ground elapsed time (GET) from liftoff are shown in Figs. 68 and 69. All requirements were met and actual coverage exceeded estimates.

2. ***Data processing and display.*** The GSFC Data Operations Branch received downrange metric data from the AFETR, generated and transmitted nominal pointing data and real-time acquisition messages for MSFN stations, excepting Bermuda which received powered flight data from the AFETR. All computer support commitments were met.

D. Ground Communications

NASCOM performance during the near-earth phase met all support requirements. With the exception of the loss of one TTY circuit to DSS 51 for 8 min and both DSS 51 voice circuits for 72 min, there were no communications problems during the near-earth phase. Both outages were caused by HF radio propagation difficulties.

Table 37. Agena Channel F spacecraft telemetry received at DSS 71 for retransmission to the SFOF

Station	From, GMT	To, GMT	Usable data, %
Tel-2	Launch	22:27:45	100
Grand Bahama Island	22:27:45	22-31:41	90
Antigua	22:31:41	22:38.05[a] (LOS)	68.8
Ascension Island	22:44:47	22:51:08	87.5
RIS Coastal Crusader	22:51:08	22:56.34	86.6
Pretoria	22:56:34	22:58:34[b]	80

[a]Loss of signal.
[b]Spacecraft separation.

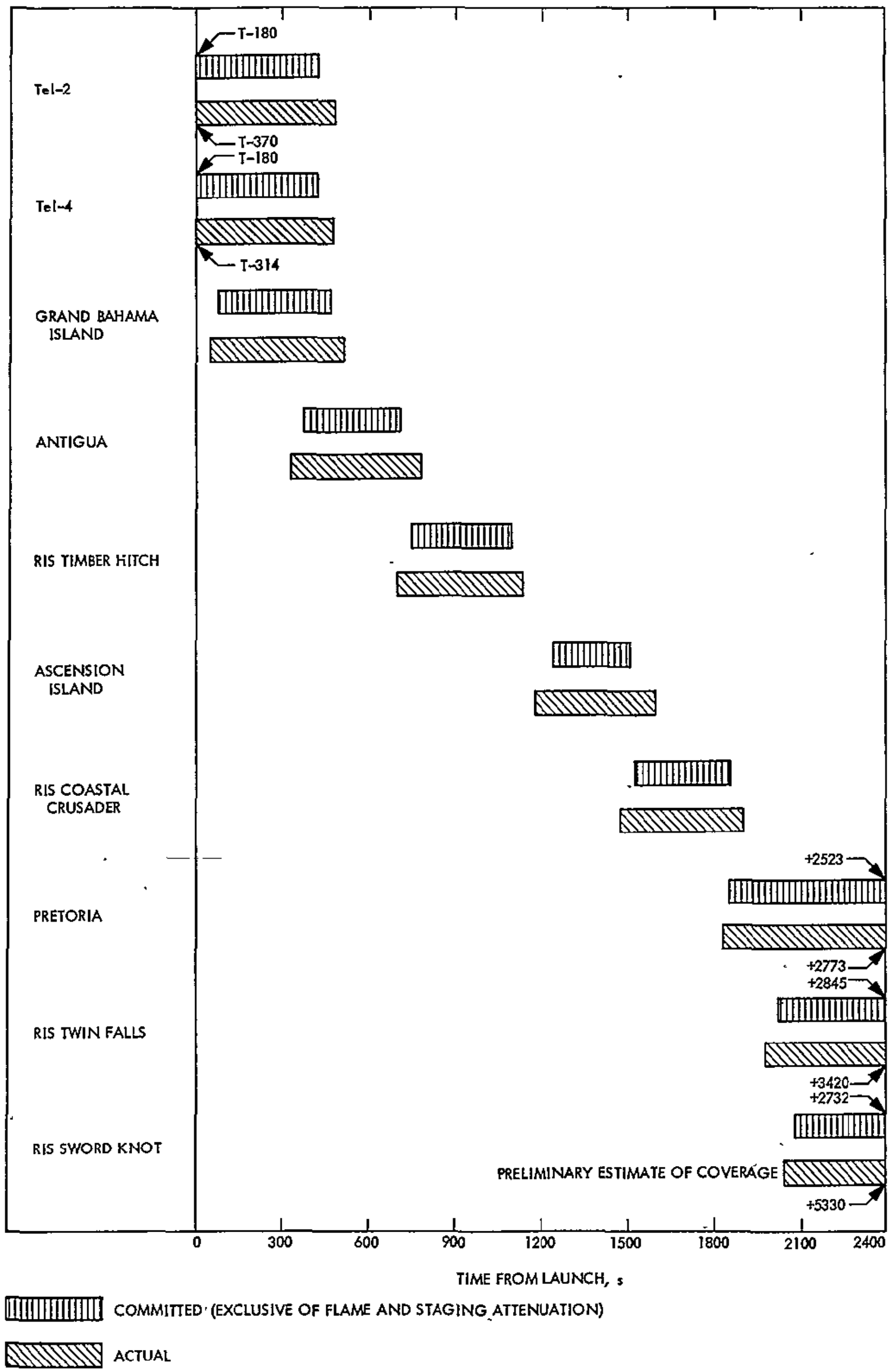

Fig. 66. Mission IV AFETR VHF 244.3 MHz telemetry coverage

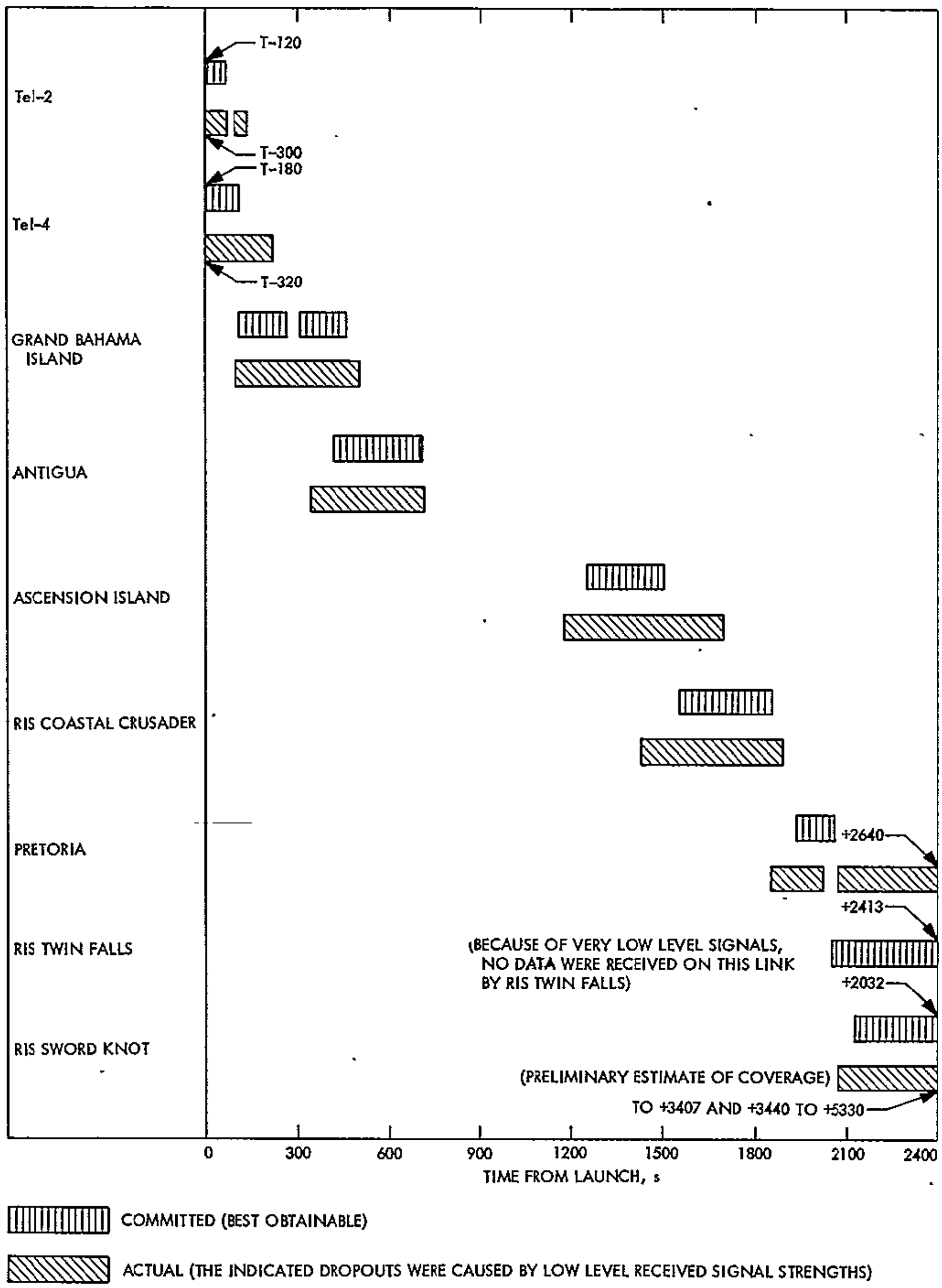

Fig. 67. Mission IV AFETR S-band telemetry coverage

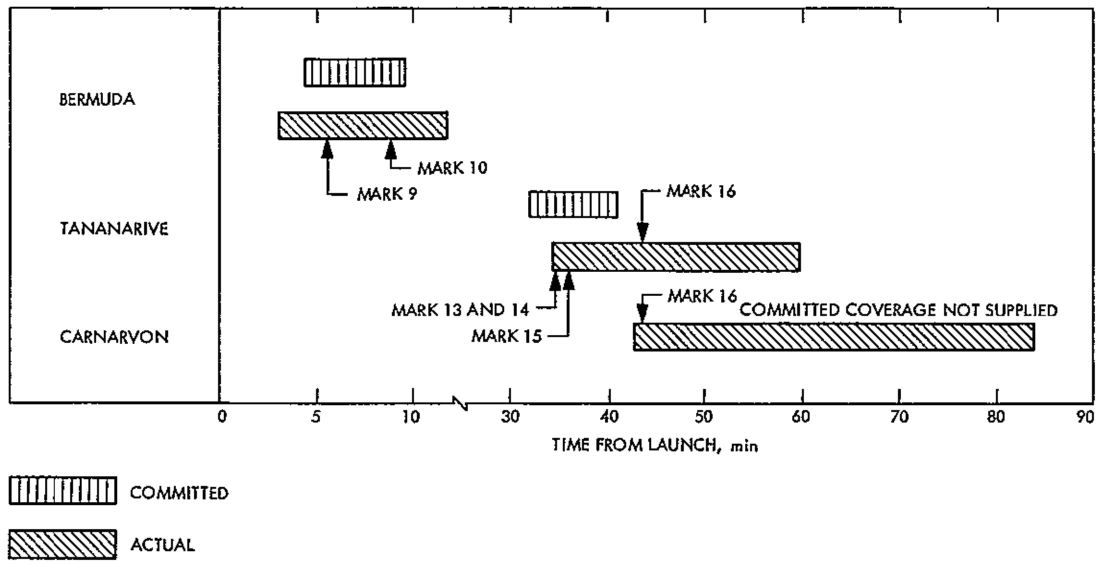

Fig. 68. Mission IV MSFN VHF telemetry coverage

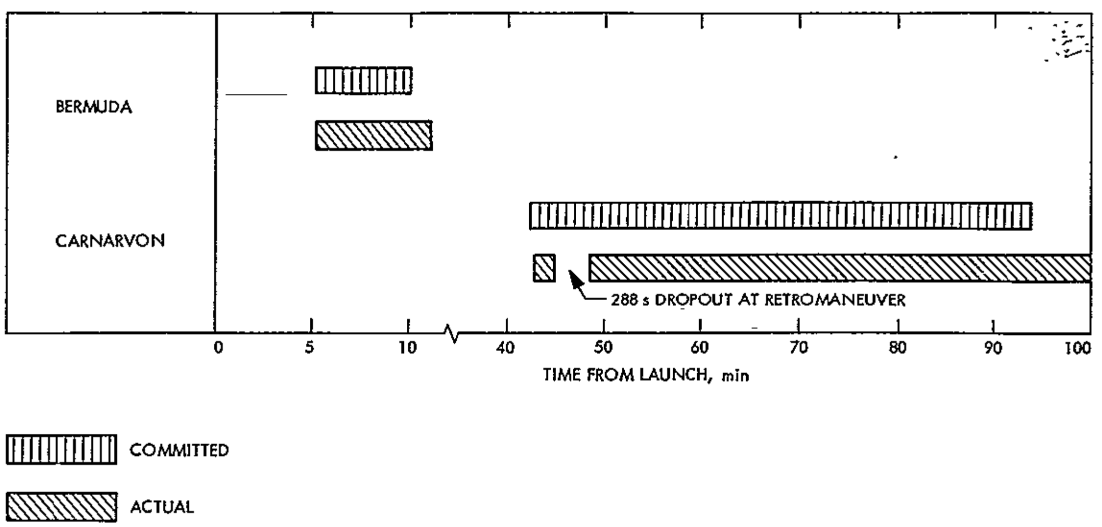

Fig. 69. Mission IV MSFN C-band radar metric coverage

The high-speed data circuits performed exceptionally well with virtually 100% reliability. DSS 62 circuit reliability was the lowest with 99.44%. The transmit side of the lines was used during the launch phase to backfeed the status net, command link, and the voice of *Lunar Orbiter* to the DSIF stations.

Table 38. Mission IV early orbit determination results

Orbit	B•TT, km	B•RT, km	Time of closest approach, GMT
Targeted aiming point from targeting specification	5,211	−2,403	15:44, for 102 deg L az
Desired aiming point for polar orbit mission	780	9,640	15:44:30
DSN orbit 1001-1 based on 26 points of Pretoria (FPS-16) tracking data	11,525	−2,640	17:45:40
1st AFETR orbit based on Pretoria (FPS-16) and RIS *Twin Falls* tracking data	10,749	−2,648	17:26:00
DSN Orbit 1001-2 based on 124 points of Pretoria (FPS-16) tracking data	11,133	−2,668	17:38:33
2nd AFETR orbit based on DSS 41 tracking data	8,148	−2,549	16:43:39
DSN orbit 1103 based on 125 points of Pretoria (13.16) and 156 points of DSS 41 tracking data	9,121	−2,911	16:54:01
Project orbit 1300 based on 131 points of DSS 41 tracking data	8,060	−2,017	16:34:00
AFETR post retro orbit based on Carnarvon tracking data	30,351	−2,289	23.09:34
DSN orbit 1105 based on 292 points of DSS 41 angle and doppler tracking data	8,716	−2,791	16 48:23
DSN orbit 1107 based on 288 points of DSS 41 doppler data only	9,150	−2,173	16:43:13
Project orbit 1214 based on 544 points of DSS 41 and 172 points of DSS 62 doppler data. The midcourse maneuver orbit	8,980	−2,760	16:48:15
Project orbit 200 based on 326 points of DSS 41, 320 points of DSS 62, and 165 points of DSS 12 doppler data. A post-flight orbit evaluation	9,005	−2,709	16:47:51

The teletype circuits were also exceptionally reliable. DSS 41 and DSS 62, the two prime stations during launch, showed better than 99% reliability. Of the secondary stations, the least reliable circuits (DSS 51) showed 98.08% reliability.

The NASCOM voice circuits performed well within expectations. The prime stations (DSS 41 and DSS 62) showed better than 99% reliability.

Special propagation forecasts were provided for all HF radio circuits during the launch phase.

Special coverage was implemented from $L - 11$ through $L + 7$ h for all NASCOM launch support circuits within the continental U.S.

E. DSN Processing of Near-Earth Metric Data

DSN metric data requirements placed on the AFETR and MSFN called for the transmission of both raw and computed launch vehicle metric data from the RTCS to the SFOF for use by the DSN FPAC team. Figures 70 and 71, and Table 38 provide a summary of the early orbit determination results computed by the RTCS and the FPAC teams.

IV. Deep Space Operations and Performance Summary

A. DSN Performance

1. *General.* DSN performance in support of Mission IV was very satisfactory with few major operational or technical problems. Due to the many spacecraft photo system anomalies, it was necessary for the DSN to react in real time to Project requirements over and above the DSN commitment. In all cases, the DSN met or exceeded its commitments during the course of the mission. Through the training and active mission support periods, the DSN supplied approximately 852 h of computer support and 993 h of DSIF tracking support. This compares with 1234 computer hours and 972 tracking hours used during Mission III.

2. *Configuration control.* Configuration in the SFOF and DSIF was controlled by SFOF change control and the Project–DSN Interface and Configuration Control Document which was updated to reflect an accurate configuration for Mission IV.

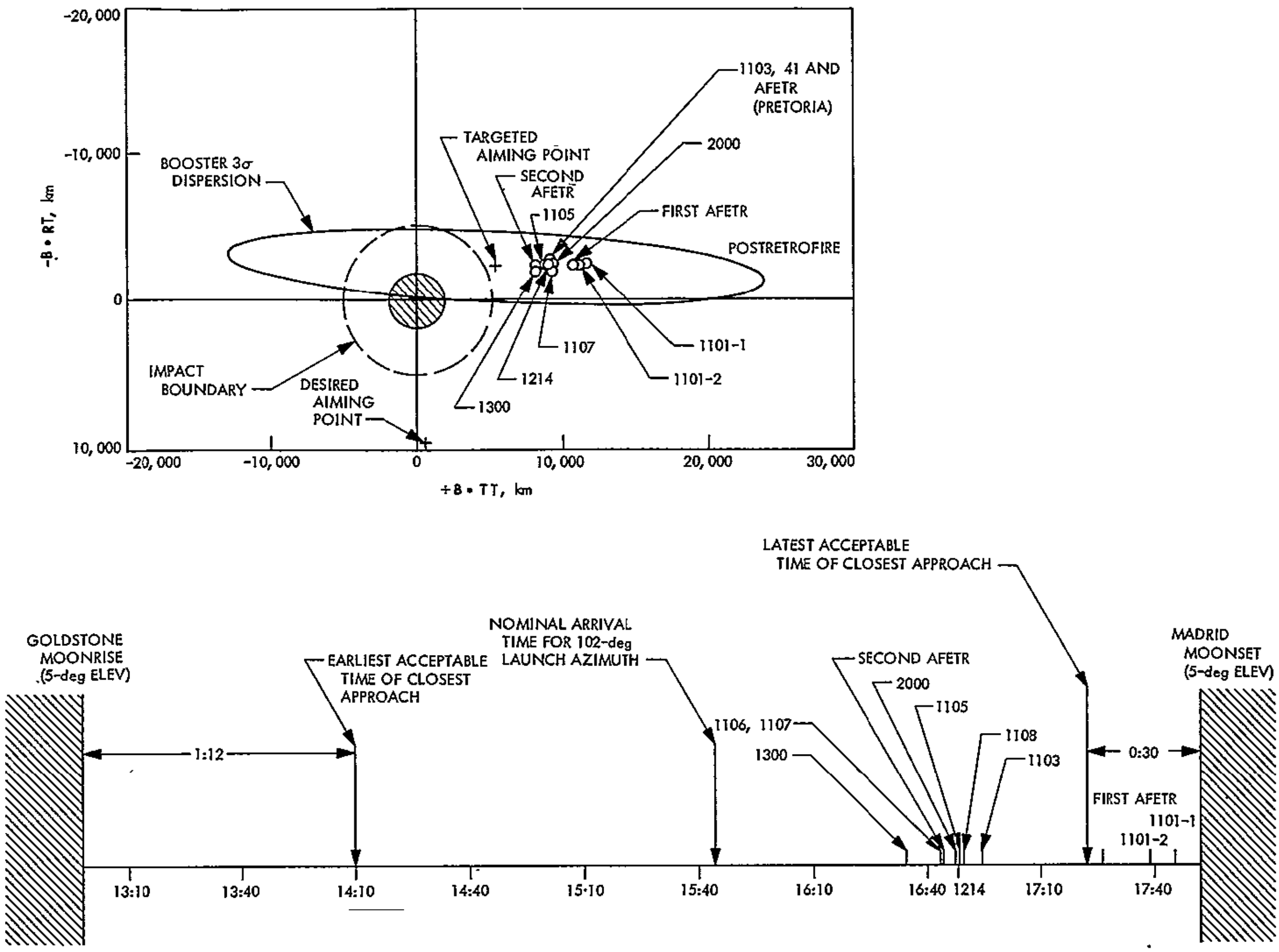

Fig. 70. Mission IV early orbit determination B-plane map

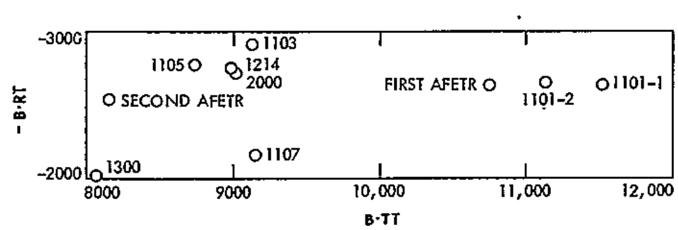

Fig. 71. Mission IV early orbit determination results

3. *Simulation.* The integration of Project software and simulation operational procedures into the new ASI 6050 simulation computer went very smoothly. This was the first time that the simulation system was operationally utilized in the manner for which it was designed, a DSN-operated facility using project software integrated with DSN software. Valuable experience in system operations was gained by the DSN which later enabled the facility to support Mission V in a better manner.

4. *Flight support.* There were no major flight support problems within the DSN during Mission IV. A series of momentary power transients within the SFOF resulted in several computer restarts, but had no real affect on the mission. Meetings with power company personnel disclosed that each failure occurred in a separate portion of their distribution system. It is interesting to note, however, that after the meetings were held there were no more outages. The SFOF wiring was modified to provide better generator support and reduce the chance of power transients during critical periods.

There were a few minor procedural and hardware problems during the course of the mission, most of which were worked out in real time.

5. *Scheduling.* The scheduling activity between Project and DSN personnel continued in a smooth manner throughout Mission IV. Project participation in this area was considered very satisfactory. A major contributing factor to the smoothness in this area was the ability of the Project to accurately forecast support periods. This was possible due to the small number of spacecraft occultations which enabled accurate predictions of station view periods.

B. DSIF Performance

1. *Overall performance.* Overall DSIF operations performance continued to be very satisfactory. The commitment was for a maximum of 899 h of tracking based on a 29-day photographic mission. The DSIF tracked a total of 783.33 h or 87.2% of the maximum commitment. Stations supporting the mission were Deep Space Stations 12, 41, 51, 62, and 71. The performance of DSS 62 was very creditable, considering its activation as a prime supporting station for *Lunar Orbiter* took place just prior to Mission III. A summary of the total coverage provided during both the photographic and extended mission phases is listed in Table 39.

Table 39. Total DSIF coverage summary for Mission IV photographic and extended mission phases

DSS	Two-way tracking, h	Three-way tracking, h	Total tracking, h	Ranging, h	Time correlation, h
12	330.40	80.49	410.90	71.84	2.31
41	241.40	74.06	315.46	37.84	1.48
51	0.00	4.45	4.45	0.00	0.00
62	273.54	63.31	336.85	49.14	1.39
Totals	845.34	222.31	1067.66	158.82	5.18

During the 29 days of the photo mission, the maximum DSN tracking commitment was 899 h. Actual tracking accomplished during this period was 783:19:39 h or 87.2% of the maximum commitment.

A total of 79:26:00 h of ranging was performed and 15 DSIF station time synchronization measurements were made.

2. *Flight summary*

a. Launch and acquisition phase. After liftoff, DSS 71 tracked the spacecraft manually for 3 min before one-way lock was lost. The signal was reacquired 30 s later and tracked an additional 4.5 min before the spacecraft passed out of range.

DSS 51 acquired the spacecraft in one-way lock at 22:56:55 GMT at a signal strength of −130.0 dBmW and tracked it a total of 8.5 min. Because of the S-band antenna equipment failure on board the RIS *Twin Falls*, the prime activity at DSS 51 was to recover telemetry. The station was prevented from using the autotrack mode because of fatigue cracks in the counterweight cage supports. Consequently DSS 51 tracked in aided track, using the acquisition aid antenna, throughout the pass. The receiver dropped lock at 23:05:00 GMT.

DSS 41 was the initial acquisition station for the mission and was in one-way lock at 23:10:28 GMT; two-way lock in autotrack was achieved at 23:13:27 GMT. Acquisition was normal at a signal strength of −96.8 dBmW.

b. Transit and lunar phase. The midcourse maneuver was accomplished at 16:45:00 GMT on May 5. Injection into near-polar lunar orbit occurred at 15:47:00 GMT on May 8. Between these two events, the DSIF stations practiced tracking and handover using a 375 Hz offset frequency. Except for the first two tracks and the first handover, the procedure was successful.

On May 9, during an eclipse of the sun, DSS 62 tracked the spacecraft across the sun's disc. A rise in system noise (>20 dB) was noted but had no impact on the mission.

Spacecraft performance was affected by the failure of the thermal door covering the camera and by other photographic subsystem operation anomalies. Work-around techniques were devised to bypass these problems.

Except for minor anomalies, the station configurations for Mission IV functioned exceptionally well.

c. Signal levels. Unlike the previous missions, the traveling wave tube amplifier (TWTA) continued to function between video readout periods. When the spacecraft attitude was changed, to normalize temperatures, the directional antenna used with the TWTA was frequently not pointed at the ground station. Therefore, received carrier power variations of 30 to 40 dB were indicative of changes in antenna pointing rather than changes in transmitted power from the spacecraft. Signal levels of −90 to −100 dBmW were nominal for the link during photo readout.

d. Station anomalies. The significant anomalies and their causes and effects on the mission are listed in Table 40. DSSs 12, 41, and 62 each had a maser failure but were able to track the spacecraft using the parametric amplifier. It was discovered that the new "F" version of the IMP also caused interference with the antenna pointing program. This interference was also present during Mission III. The "E" version of the IMP was used subsequently.

3. DSIF operations

a. Multi-spacecraft tracking. Multi-spacecraft tracking operations were significantly different from previous missions with respect to the tracking and handover of the spacecraft. Beginning with the initial orbit, the spacecraft was tracked using a synthesizer frequency biased at times as much as 460 Hz at the VCO. The VCO acquisition frequencies were also biased by an equal amount for handover from one station to another. The finalized working procedures resulted in published predicts containing a biased synthesizer frequency with all other data being nominal. Station transfers were conducted with the outgoing station remaining on the biased synthesizer frequency until transmitter turn-off time. The incoming station turned on their transmitter at a biased VCO acquisition frequency comparable to the outgoing biased synthesizer frequency. Special procedures were devised to reacquire the spacecraft uplink at 200 W transmitted power and then to tune rapidly to the synthesizer frequency to avoid acquiring *Lunar Orbiter II* and *III*. This procedure proved very successful and only one acquisition failure occurred, when the DSS 62 transmitter was turned off 4 s early. Reacquisition using the new procedures was rapid and smooth.

b. Command procedures. Command procedures were normal and were not affected by the offset tracking procedures. Command static phase error limits during the mission were changed to ±8.5 deg. Many additional commands were required to work around the spacecraft photography package failures.

4. Tracking data analysis

a. Performance summary. The DSIF SDA group provided around-the-clock support from launch through the end of the photographic phase of the mission and on a one-shift-per-day basis until completion of photo readout. The group's function was to provide liaison and coordination between the deep space stations where the tracking data originates and the DSN and Project FPAC groups who are the data users. The group activities included tracking data monitoring and data quality assessment for the FPAC Orbit Determination Group, frequency inputs to the ODP, acquisition predicts to the deep space stations, and consultation with the DSIF Operations Engineering Group on the solutions to problems.

The performance of the DSIF tracking data system during Mission IV was excellent. There were no major data outages and the good data averaged better than 90% of the total data received. Because of the two additional spacecraft, which were in orbit around the moon, requiring offset frequency tracking, some difficulty was encountered at first when the stations locked onto sidebands instead of the main carrier. A great deal of care was taken to instruct the stations regarding tuning when coming into three-way lock. Considering the difficulty of acquiring the spacecraft at an offset frequency during station handover, there were very few times when the uplink was lost.

b. Predicts generation. There were no operational problems in this area. Predicts which included the offset frequency were reliably used by the stations to acquire the spacecraft and were generated on time.

c. Tracking data handling. There were no problems reported in this area.

d. Tracking data monitoring. Tracking data were backfed to the Goldstone computer facility and processed by the TDM program. The received data were compared with a set of predicts, which was either internally generated or received from the SFOF, and the residuals were computed. The standard deviation of the last five points was calculated and used to determine an estimate of the data noise. The output was transmitted to the SFOF by teletype and printed in tabular form, and also displayed on an XY plotter. During the cislunar phase the residuals showed bias errors of less than 1 Hz and noise errors of less than 0.1 Hz, indicating high-quality data.

Figures 72 and 73 show the results of SDA monitoring of spacecraft velocity maneuvers.

5. Ranging and time synchronization

a. Ranging operations. Due to the extended lunar mapping objective of the photographic mission, the

Table 40. Mission IV summary of DSIF anomalies

DSS	Day	Time, min	Anomaly	Probable cause	Remedy	Effect on mission	Comment
62	126	10:00	Beam voltage overload	Sticking relay	Reset	2 min of tracking data lost	Random failure
62	127	07:51	Transmitter shutdown	Beam voltage relay open	Bypassed, changed after track	6 min of tracking data lost	Random failure
12	127	16:48	Transmitter shutdown	Heat exchanger pump overload	Reset, changed pump motor	No two-way track 17.08–20:25	Random failure
12	127	17:08					
12	128	22:53	Antenna failed to track in hour angle	Bad low-speed integrator	Replaced	None (DSS 41 in two-way)	Random failure
62	129	11:25	Inability to range	Solar noise	Decreased integrator switch setting	None	Tracking near sun
62	129	16:00	Antenna pointing program reset	Interference from IMP	Replaced IMP "F" with "E"	None	Common failure
41	130	02:09	Antenna emergency stop operated	Vibration caused oil level switch to trip	Reset	None	Random failure
41	130	05.09			Inhibited stop	None	
62	130	05.00	Maser would not cool	Sticking valve in crosshead	Switch to paramp replaced crosshead	None	Random failure
62	130	06:43	Spurious "SOM" in TDH	Poor calibration	Recalibrated	None	Common failure
12	130	12:25	DIS inoperative	Improper seating of time select flip-flop	Used autotrack	None	Common failure
41	130	22:45	Maser freezing	Contaminant in subsystem valve	Monitored	None	Random failure
41	131	03:55	Maser inoperative	Contaminant in subsystem valve	Switched to paramp, warmed system, and purged	None	Random failure
12	132	14:45	Maser inoperative	Contamination of high pressure circuit	Switched to paramp	None	Random failure
62	133	09:30	Transmitter high power overload	Meter overshoot	Reset	2 min of tracking data lost	Random failure
12	133	22:30	TDH data failure	Bent pins in TDH patch panel	Straightened and replaced	None	Random failure
41	136	07:00	FR 1400 Recorder inoperative	Defective head	Removed from service	None	Random failure
62	136	10:41	Maser inoperative	Sticking valve in crosshead	Switched to Paramp Replaced crosshead	None	Random failure
41	139	13:58	Spurious "O" in TDH data	Poor calibration	Switched to punch 2	3 s of video lost	Common failure
62	139	22:35	Transmitter shutdown	Arc detector activated	Reset	5 min of tracking data lost	Random failure
12	140	01:00	Excessive noise	Faulty synthesizer	Replaced	None (track transferred to DSS 62)	Random failure
12	140	07:33	Missing digit in TDH data	Faulty patch board "13"	Replaced with Format 2	None	Common failure
12	142	07:35	Incorrect data on TDH	Faulty patch board "13"	Replaced with Format 2	None	Common failure
12	142	01:16	CEC Recorder inoperative	Shorted power cord	Repaired	None	Common failure
62	142	21:50	FR 900 inoperative	Defective head	Replaced	None	Common failure
12	143	00:40	Maser inoperative	VAC-ION pump circuit breaker tripped	Switched to Paramp Normal maser cool-down	None	Common failure
62	143	02:38	Maser inoperative	Sticking valve in crosshead	Switched to Paramp Replaced crosshead	None	Common failure
62	144	21:10	Transmitter shutdown	Forward power meter relay interlock	Reset interlock	2 min of tracking data lost	Common failure
12	145	11:37	Synthesizer lost lock	System transient	Relock synthesizer	2 min of tracking data lost	Random failure
12	147	16:54	FR 900 inoperative	Defective head	Replaced	None	Random failure

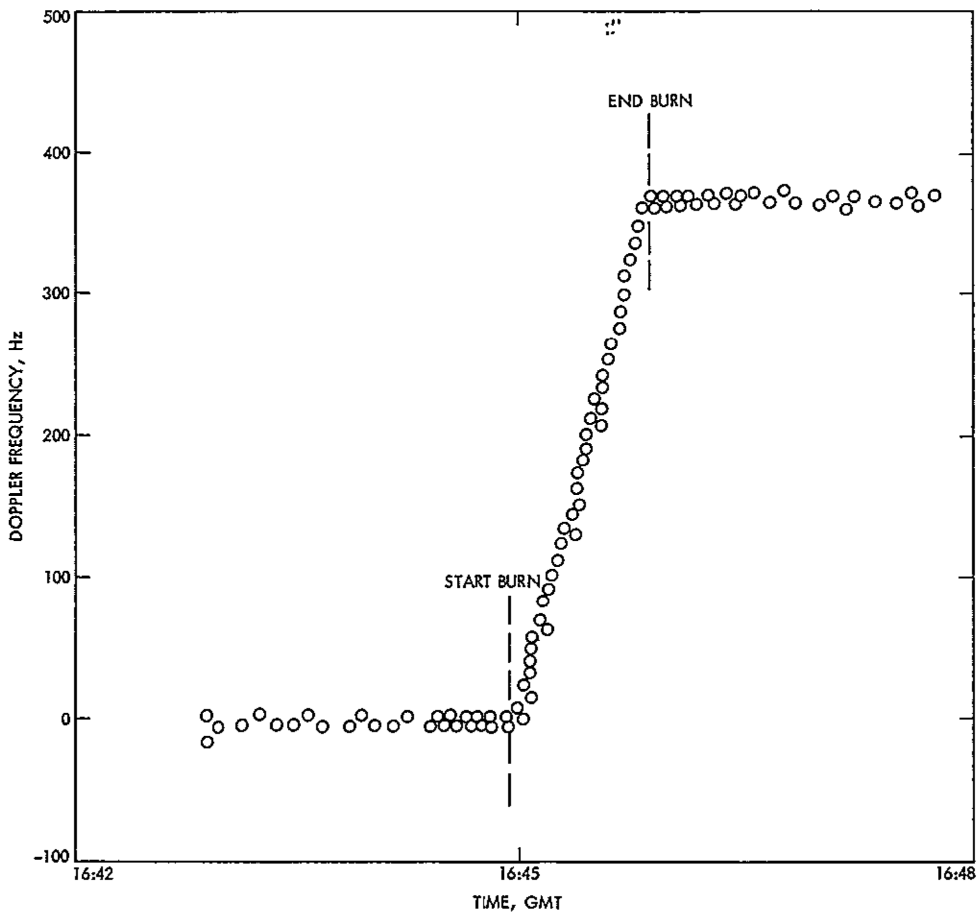

Fig. 72. Mission IV midcourse maneuver doppler shift

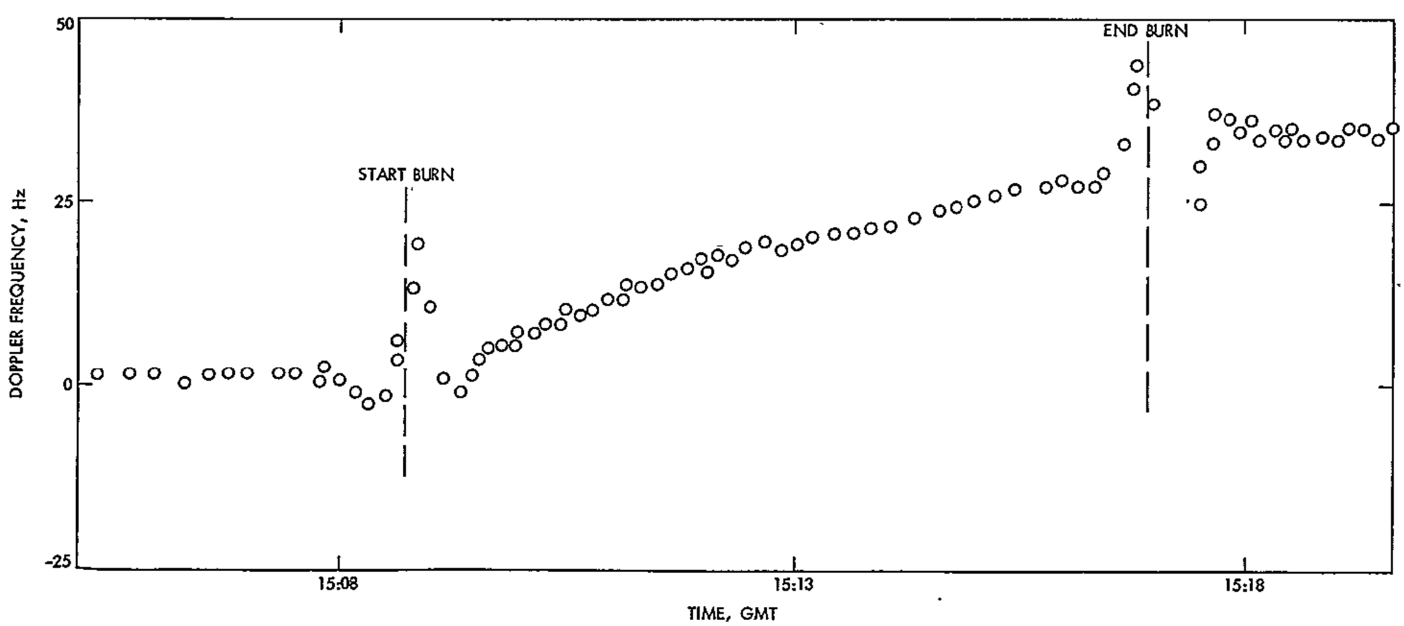

Fig. 73. Mission IV orbit injection maneuver doppler shift

majority of the ranging data was taken during the cislunar phase of the mission. Ranging operations were not performed during photo readout.

b. Time correlation. Time correlation measurements were made to determine the time offset between the master station clocks at two separate stations during the same time period. The time difference (bias) was inserted into the ODP to update the time tags on the tracking data supplied by each station. The measurements were taken during the period from May 4 through May 11, 1967, when the start of the picture-taking phase precluded further measurements until the mission was completed. The participating stations were DSS 12, DSS 41, and DSS 62.

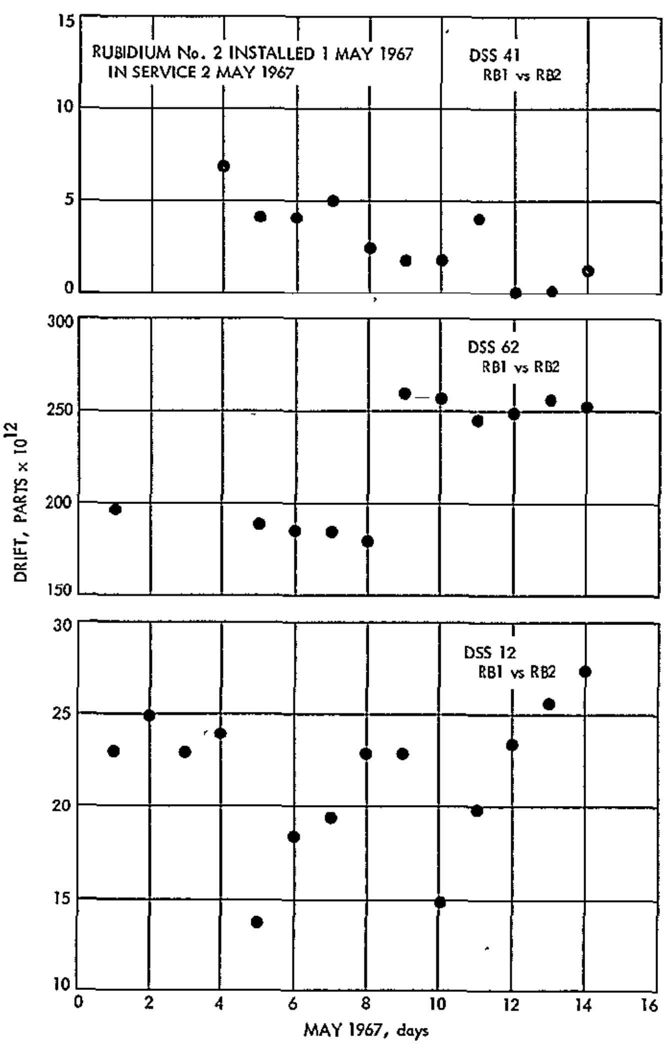

Fig. 74. DSS rubidium standard drift measurements

Figure 74 shows the drift of the station rubidium standards. Rubidium No. 2 at DSS 41 had been on loan to another station and was not installed until May 1. Figure 75 shows the drift of the VLF receivers. Figure 76 shows the clock difference between the PC-141 clock and the time code generator. Table 41 lists the actual time difference between the stations. The time given in GMT is at the midpoint of the measurements.

The clock division errors shown in Fig. 76 for DSS 41 and DSS 62 are reflected in the time correlation measurements contained in Table 41 and Fig. 77 and agree quite closely.

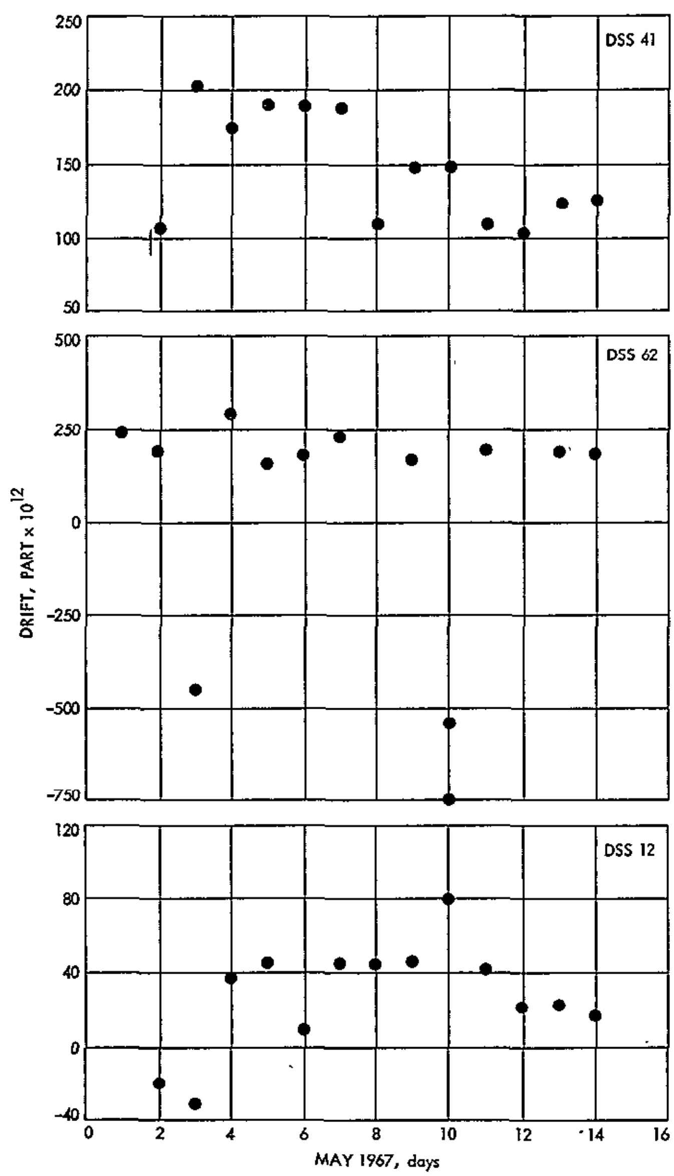

Fig. 75. DSS VHF receiver drift measurements

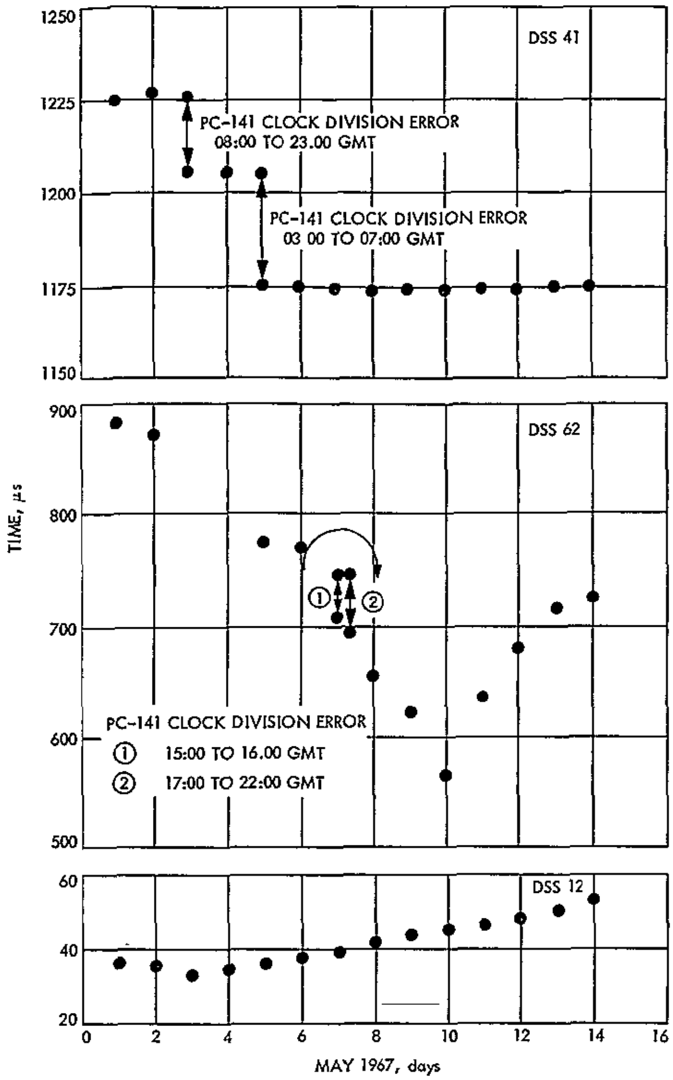

Fig. 76. Difference between DSS primary and secondary time references

C. GCF/NASCOM Performance

GCF/NASCOM performance during Mission IV was, again, exceptionally reliable. Problems were minimal during all phases of the mission.

1. High-speed data lines. This portion of the communications system again performed exceptionally well during all tests and mission phases with virtually 100% reliability. The DSS 62 circuit had the lowest reliability with 99.4%. The transmit side of the lines was used during the launch phase to backfeed status information and the command link to the DSIF stations.

2. Teletype circuits. The teletype circuits were also exceptionally reliable. The three prime stations during launch (DSS 12, 41, 62) showed better than 99% reliability. Of the secondary stations, the weakest circuits were to DSS 51 with 98.08% reliability.

3. Voice circuits. The NASCOM voice circuits provided for the *Lunar Orbiter IV* Mission and tests performed well within expectations. The DSS 41 voice

Table 41. Mission IV DSIF time synchronization measurements

Date May 1967	Time, GMT	Stations		Difference, μs
		DSS	DSS	
5	20.46	41	12	768.9
6	14:22	62	12	307.5
6	21:20	41	12	756.1
7	06:14	41	62	365.3
7	14:20	62	12	321.4
9	06:20	41	62	384.2
9	17:26	62	12	379.6
10	23:40	41	12	762.3
11	00:32	41	12	780.9

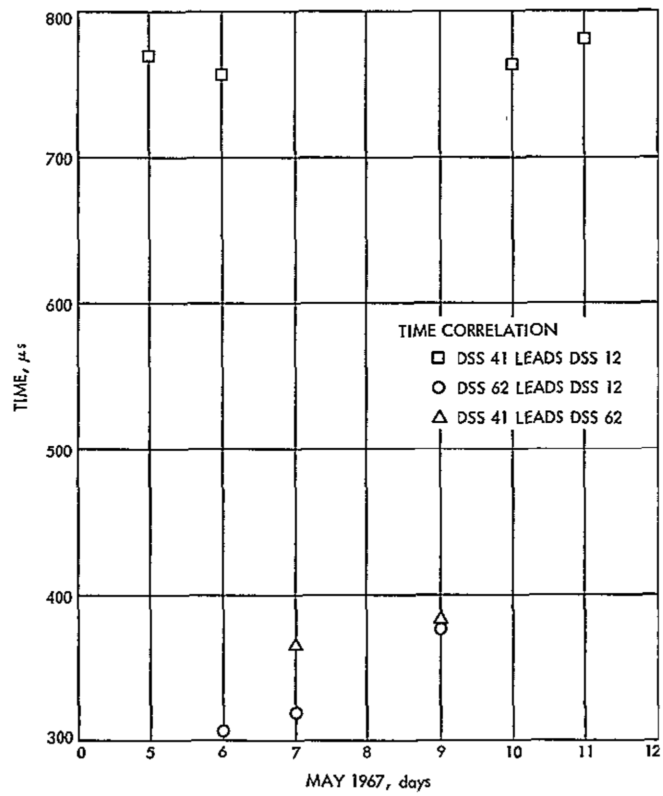

Fig. 77. DSIF Station time correlation

on IBM cards during the mission-critical phases (launch, midcourse, lunar injection).

The following general functions for monitoring tracking and telemetry data were performed by the DSN Monitor Team:

Table 42. Backup tracking data furnished to the *Lunar Orbiter* Project

DSS	Day	Pass	Time, GMT	Reason
62	128	4	13:00–17:30	To simplify procedures. No equipment problems.
12	128	4	13:00–17:30	To simplify procedures. No equipment problems.
12	134	9	00:35–02:35	Program out glitches.
12	135	11	20:35–20:47	Not patched to computer.
12	137	12	00:00–01:26	Time print incorrect.
12	137	12	01:26–01:38	DPS wiped out editor storage.
12	137	12	02:13–08:03	Backup for switch to another computer string.
41	137	13	06:28–14:23	Backup for switch to another computer string.
12	138	13	02:00–09:85	Remake master file.
41	138	14	06.58–10:25	Remake master file.
41	139	15	13:50–14:02	Bad data due to bad TDH punch board connector.
12	140	15	00:00–01:00 05:27–08:10	Had to remake file due to bad time-tagged data.

(1) Monitoring of all incoming tracking and telemetry data.

(2) Ascertaining that tracking and telemetry data were received in the proper format.

(3) Logging information pertinent to the received data.

2. *Tracking data validation.* Tracking data validation consisted of continuous monitoring of incoming data for: (1) correct preambles (data identification codes) inserted at the appropriate times; and (2) proper AFETR and DSIF formats. Information such as total data points received, data condition codes, anomalies, etc, were logged. Reperforators and IBM 047 tape-to-card punches were used to provide a backup tracking data source during the mission-critical phases. Cards were punched from L to $L + 6$ h, from midcourse -2 h to midcourse $+1$ h, and from injection -2 h to injection $+2$ h. Reperforator tapes were produced throughout the period from launch to injection $+2$ h. Additional cards were punched during the support period as requested by the Project. Table 42 details the support requested and furnished to the Project.

Primary data losses were due to communication failures which injected extra characters into the data stream or caused garbling of the tracking data. During normal operation, bad data condition codes caused the majority of unusable samples. Tracking data results are summarized in Table 43.

Table 43. Mission IV tracking data monitoring summary of the DSN

Description[b]	Data source					Total
	DSS 51	AFETR	DSS 41	DSS 62	DSS 12	
Total tracked, s	15780	4075	509998	615600	590080	1735533
Total good data, s	14940	3739	491689	587500	561769	1659637
Total bad data, s	730	336	12440	21240	19500	54246
Total garbled data, s	300	126	9350	13190	9933	32899
Usable data, %	92.78	88.66	94.61	93.34	93.57	93.78
Bad data, %	4.63	8.25	2.44	3.45	3.30	3.13
Garbled data, %	1.90	3.09	1.83	2.14	1.68	1.90
No data received, %[a]	0.69	0.00	1.12	1.07	1.45	1.19

[a]No data received is due to samples lost when changing sample formats and rates plus short duration communication outage data losses which were not recovered by playback.
[b]All numbers and percentages referenced to a one-second time base.

circuit was the weakest with approximately 86.42% reliability. The other prime stations (DSS 12 and DSS 62) showed better than 99% reliability during all tests and mission phases.

4. JPL–Goldstone microwave system. The Goldstone–SFOF microwave system operated by the Western Union Company provided excellent communications service with 99.76% reliability.

D. SFOF Performance

1. Data Processing System. The overall performance of the Data Processing System was very acceptable. There were no major software or hardware failures during the mission and minor problems which did occur were random in nature. Mission IV was supported with a total of 852 computer hours over a 30-day period.

a. Central computing complex. The communications problem between the 7044 and the 7094 which was present during each of the previous missions was again present during Mission IV. The anomaly was commonly known as the COMERR 1 problem because the computer would first print COMERR 1. Each restart required approximately 2 min for the system to return to Mode II operation. There were 77 COMERR 1 problems during MISSION IV. The resultant data loss was not significant, however.

b. Software problems. All software problems were minor in nature. At $L + 5$ days teletype transmissions from the 7044 input-output computer were not transmitted correctly due to a software bug. A bulk printer had been inadvertently assigned the same core storage buffer as a teletype subchannel. When an output was requested on the bulk printer, the data would also be sent out on the TTY subchannel. The problem was alleviated by not using the bulk printer. There was no loss in display capability since other printers were readily available.

When switching from one computer string to another, some of the common environment data were not transferred. The problem was found in the programming and corrected.

c. Hardware problems. In general, hardware performance was good. There were 4 power failures which resulted in 109 min of data loss. Data loss for the entire mission was less than 0.25%. A number of printer, plotter, and card reader failures occurred in the user areas which were quickly corrected by maintenance personnel.

2. Training and staffing. The DACON position (Software Coordinator) was again staffed by Boeing Company personnel who performed exceedingly well. Revised DACON procedures were published on time and proved extremely useful.

3. SFOF operations. The most significant problems affecting operations were the four commercial power failures. These occurred within an 8-day period. Each power drop was an unrelated, individual power company problem. The effect of the failures was to shut down air conditioning, computers, simulation system, and the CP.

The Operations Control Area display system showed a notable improvement over previous missions. This was partially due to the quality of the display material supplied by the Project, and partially to the interest applied by the display operators.

The data distribution system functioned smoothly with no problems reported. The data handling function performed by SFOF Document Control was smooth with no serious problems encountered.

E. DSN FPAC Performance

The tracking data quality was excellent for the entire active mission. Anomalies in transmitter reference frequency were the primary source of most of the fitting problems in the orbit determination solutions. These anomalies plagued each mission and were reported as undesirable in all previous TDQD reports.

The transmitter reference frequency along with the raw tracking data are the primary inputs to the ODP. The reference frequency number could not always be obtained directly from the teletype listing of the raw tracking data. The number was not included in the ranging data format whenever ranging data were used.

The DSN FPAC-Project interface functioned smoothly and cooperatively. There were no particular problems in any area except the procedure for checking transmitter frequencies.

F. DSN Monitor System Performance

1. Performance summary. High-level multiproject activity limited the DSN Monitor System operations to a 16-day period from launch on May 4 through May 20. Activities included monitoring and validation of both tracking and telemetry data received via teletype and high-speed data lines. Backup tracking data was punched

3. Telemetry data validation. All telemetry data received via teletype were monitored for the following:

(1) Insertion of correct preambles at appropriate times.

(2) Proper headers.

(3) Proper number of blocks (lines) per TCP edit mode.

(4) Proper number of characters per block.

(5) Proper frame sync.

(6) Proper Δt between frames.

(7) Correct GMT.

(8) Parity errors.

All anomalies observed were logged and categorized as either a DSN responsibility or a Flight Project responsibility (e.g., attributable to the spacecraft). The total number of frames and the total number of blocks containing anomalies were tabulated. The results of these tabulations, together with their corresponding percentages, are summarized in Table 44.

Telemetry data received via the high-speed data line was monitored for the first time during Mission IV. GCF line outages and data anomalies were cross-checked with the data received via teletype. Due to software problems the high-speed data output in the monitor area was terminated approximately 8 h prior to lunar injection.

4. Conclusion. Data quality and quantity for Mission IV compared quite favorably with the DSN Monitor Team figures compiled for the Missions II and III. Slight increases in the percentage of usable data received at the SFOF were noted in both telemetry and tracking data. The majority of outages were caused by GCF transmission errors.

Table 44. Mission IV telemetry data monitoring summary of the DSN

Description	DSS				Total
	71	41	62	12	
Total passes	1	16	16	16	49
Total frames monitored	243	17329	21423	21432	60427
Total number of good frames received at SFOF	197	16253	20421	21052	57923
Good frames received, %	81.07	93.79	95.32	98.23	95.80
Total blocks monitored	1458	95303	119154	113355	329270
Total number of good blocks received at SFOF	1188	92521	115781	111815	321305
Good blocks received, %	81.48	97.08	97.17	98.64	97.58
Total number of bad[a] frames	46	1076	1002	380	2504
Bad frames, %	18.93	6.21	4.68	1.77	4.14
Total number of bad[a] blocks	270	2782	3373	1540	7965
Bad blocks, %	18.52	2.92	2.83	1.36	2.42

[a]A bad frame or block is defined as one which violated one or more of the criteria set forth in paragraph F. 3. of this section.

Part VI. *Lunar Orbiter V*

I. Introduction

A. Mission V Objectives

Completion of the primary *Apollo* photographic objectives during the first three missions permitted concentration on scientific goals during the final two missions. Mission IV provided coverage of more than 99% of the nearside of the moon at resolutions approximately 10 times better than earth-based observations. These photo results along with farside photo coverage obtained during Missions I through IV, were used to select interesting targets for Mission V on the near and far sides of the moon as well as supplemental photography of candidate *Apollo* sites.

The secondary objectives for Mission V were essentially the same as for the previous missions: (1) to provide precision trajectory data for use in improving the definitions of the lunar gravitational field; (2) to obtain micrometeoroid flux and radiation dose measurements of the lunar environment, primarily for spacecraft performance analysis; and (3) to provide a spacecraft in lunar orbit for exercising and evaluating the MSFN tracking network and *Apollo* orbit determination program.

B. Mission V Summary

Mission V was successfully launched from Complex 13, at Cape Kennedy at 22:33:00 GMT, August 1, 1967, on a flight azimuth of 104.8 deg. Unscheduled holds, required for replacement of the *Agena* velocity meter and for locally severe weather conditions, used 144 min of the 231-min launch window for August 1. Analysis of AFETR metric and telemetry data indicated very satisfactory performance by the first- and second-stage vehicles. The *Agena*–spacecraft combination was placed in a 100-mile-altitude parking orbit for approximately 20 min and then injected into the cislunar trajectory; the spacecraft was separated from the *Agena*, automatically completed its antenna and solar panel deployment sequences, and acquired the sun. A single midcourse velocity correction of 29.76 m/s was successfully performed 31:30:00 h after launch.

Insertion into the initial, high periselenium orbit (6,028 km) occurred 92:15:00 h after launch. Photography was begun during the second orbit to obtain pictures of the desired farside areas. During the fourth orbit the spacecraft was placed in its low periselenium orbit (100 km) and farside photography was continued until Orbit 10 when a second transfer maneuver was performed to reduce the aposelenium from 6,083 to 1,499 km. Nearside photography was initiated during Orbit 15. During the 74 periods in the final orbit, 41 nearside and 13 farside photo sites were photographed.

Final readout began on August 19 and ended on August 27. One micrometeoroid hit was recorded during the mission but had no detectable effect on the spacecraft.

Most of the requirements placed on the TDS for support of this final mission were met and, in many areas, exceeded.

II. Preflight Readiness

A. General

The preflight readiness of the TDS was established by means of DSN Compatibility, Verification, and Readiness Tests, a DSN Readiness Review, and a Near-Earth Readiness Review. The reviews were held approximately 2 wk prior to launch and were organized to determine the capability of each TDS element to support the mission. Existing and anticipated problems were discussed and a time schedule for their resolution was established. The results of these reviews were then submitted by the TDS Manager to an overall Flight Readiness Review which was conducted by the *Lunar Orbiter* Project at Cape Kennedy.

B. Preflight Tests

Preflight testing for Mission V followed the test plan and philosophy described in Part I, Section VI, of this report. The plan included:

(1) Spacecraft-DSIF Compatibility Verification Tests.

(2) DSIF-MDE Tests.

(3) Software Integration and Verification Tests.

(4) Near-Earth Phase Tests.

(5) TDS Operational Readiness Tests.

1. Spacecraft-DSIF Compatibility Tests. Spacecraft-DSIF Verification Tests were conducted at DSS 71, Cape Kennedy, to verify the compatibility of the spacecraft with the DSIF configuration. During the testing, a phase reversal was discovered in the spacecraft transponder ranging code which caused the ranging system to read the range numbers improperly. The anomaly had also been present in the Mission II spacecraft and the same work-around technique was employed—namely, to accommodate the reversal by inserting minor changes in the FPAC orbit determination programs.

2. DSIF Configuration Verification Tests. Configuration Verification Tests were conducted during the month of July at DSIF stations 12, 41, 51, 62 and 71. These tests verified that the participating stations were in the proper functional configuration and ready to support Mission V. Because of commitments to the *Surveyor* Program, DSS 51 was unable to perform all of the required configuration tests for *Lunar Orbiter.* In lieu of a complete test sequence, tests performed earlier in the month to demonstrate support for *Surveyor* were accepted as confirmation of the station's capability to support *Lunar Orbiter.*

3. DSS 11 earth orbiter backup. In response to a request from the Project, DSS 11 was configured for earth-orbit tracking of the spacecraft. In the event of an *Agena* second burn failure, an alternate earth-orbit sequence was stored on board the spacecraft. Activation of the sequence required a real-time command which could only be transmitted from Goldstone. Microwave links for sending commands and receiving telemetry were established between DSS 11 and the mission-dependent equipment installed at DSS 12. The configuration was tested a week prior to launch using the *Lunar Orbiter II* spacecraft as a test vehicle.

4. Near-Earth Phase Tests. Near-earth phase testing consisted of configuration tests, data flow tests, and culminated with the TDS operational readiness tests.

5. TDS Operational Readiness Tests. Combined system tests of the AFETR, MSFN, NASCOM, and DSN were conducted on July 24, 27, and 28. Many problems were encountered during the first test and results were termed unsatisfactory. Much of the difficulty was caused by poor HF radio propagation which either delayed or prevented the checkout of AFETR and MSFN telemetry stations. Typical problems were:

(1) DSS 51 was unable to provide tracking data in the proper format.

(2) The AFETR RTCS did not reformat Tananarive metric data for transmission to the SFOF.

(3) Carnarvon simulated metric data was based on an erroneous liftoff time.

(4) Simulation packages used by the near-earth and deep space stations contained incorrect notations

such as wrong time tags, spacecraft ID, and other data format inaccuracies which caused processing difficulties, particularly at the RTCS.

(5) Static point data from DSS 41 and DSS 51 were received approximately 20 min later than scheduled.

(6) Simulated metric data from Ascension Island was not usable due to an on-site computer problem which produced an elevation below zero degrees.

(7) Carnarvon data were not usable due to garbling caused by the reformatting computer during transmission from GSFC. Post-retro elements based on Carnarvon data were late by 20 min because of the garbling.

Because of the poor performance during the first ORT, an additional test was scheduled and performed on July 27. Communications were normal and test results were classified as successful. The third ORT was conducted on July 28 and was also classified as successful.

C. DSN Readiness Review

The DSN Readiness Review for Mission V was held at JPL on July 7, 1967, in preparation for the Flight Readiness Review to be held at Cape Kennedy on July 11, 1967. There were no major changes in either operations or facilities and preparations for Mission V were essentially the same used for Mission IV. DSN loading during the launch and photographic phase was particularly heavy due to support requirements for *Surveyor, Mariner,* and *Pioneer*. Scheduling of DSN coverage was governed by an unofficial set of priority guidelines provided by the DSN managers for the various projects. Meeting the minimal support requirements for the two previously launched *Lunar Orbiter* spacecraft was not a problem.

One potential major change to *Lunar Orbiter* operations was the JPL CP. The CP was currently being used to support *Lunar Orbiter* extended mission operations; however, the Project's choice to remain with the "hardwire" system during the Mission V photographic phase eliminated any potential training or operational problems in this area.

D. Flight Readiness Review

A Flight Readiness Review involving all Project and TDS elements was held on July 11, 1967, at Patrick AFB. With the exception of a few minor problems, all elements of the TDS reported ready to support the upcoming operational readiness tests and the Mission V launch.

With respect to metric support, the C-band radar at Pretoria was not operationally ready while waiting for the arrival of a spare part which was expected on July 28. The C-band radar at Tananarive was to participate on an engineering test basis only. The importance of Tananarive data was stressed by AFETR as a backup to the Pretoria and Carnarvon radars.

A small gap in S-band coverage was predicted to occur at separation between launch azimuths 102 and 106 deg. Several gaps in VHF coverage were predicted for all three days of the launch opportunity. AFETR requested the use of telemetry aircraft to help minimize these gaps.

III. Near-Earth Operations and Performance Summary

A. Countdown and Flight Analysis Summary

The countdown was initiated on August 1, 1967 at 11:34:00 GMT ($T - 455$ min) with liftoff scheduled for 20:09:00 GMT at the beginning of a 231-min launch window. Operations progressed normally during the early part of the count. Unscheduled holds were subsequently required to replace a faulty *Agena* velocity meter and for severe local weather conditions which included rain, lightning, and gusty winds. These holds totaled 144 min of the 231-min launch window. Failures were experienced with the Patrick AFB radar, the DSS 11 maser, the Grand Bahama Island S-band antenna, and the Carnarvon FPQ-6 radar. With the exception of Carnarvon, all of these problems were cleared before launch. During the built-in hold at $T-7$ minutes, the Mission Director elected to delete all Project launch phase coverage requirements except the requirement for VHF telemetry during the interval from *Agena* second burn -20 s to cutoff plus $+20$ s. The decision was based on the Project's strong desire for lunar farside photography which could only be achieved by launching on the first day of the opportunity. The Mission Director was also aware that the decision could have resulted in the loss of metric data for orbit determination and DSN acquisition. A strong factor in this decision was an assurance by the TDS Manager that DSS 41, the initial acquisition station, could acquire the spacecraft on a nominal trajectory without additional launch information assistance. The count resumed on schedule at $T-7$ min and progressed normally down to liftoff. The time of first motion was recorded at 23:33:00.338 GMT, August 1.

The near-earth support station configuration for Mission II is shown in Fig. 78. Nominal versus actual near-earth mark event times are listed in Table 45. In all cases the difference between actual and nominal times was within tolerance. Table 46 lists the GMT of the marks, as reported in near-real time, and the reporting source.

The only major failure during the near-earth phase was the absence of S-band telemetry data from the RIS *Sword Knot.* Class I S-band coverage requirements for the interval after *Agena*-spacecraft separation were not achieved because the RIS *Sword Knot* was unable to achieve receiver phase lock.

B. AFETR Performance

1. C-band metric data. Committed versus actual metric coverage is shown in Figs. 79 and 80. All Class I metric requirements were met with downrange stations to Antigua providing continuous coverage to $L+780$ s. DSS 72 (Ascension) participated unofficially on a non-interference basis as a training exercise. A short dropout in Pretoria coverage was expected due to a deep null in the spacecraft antenna pattern; the three-min gap shown in Fig. 80 was not expected, however.

2. VHF and S-band telemetry data. Committed versus actual VHF and S-band telemetry coverage is shown in Figs. 81 through 84. Good VHF data were obtained from all stations and all VHF requirements, including spacecraft telemetry received via the *Agena* channel F VHF telemetry link, were met. Channel F data were selected

Table 45. Mission V nominal vs actual mark event time

Mark	Event	Time from launch: Nominal, s	Time from launch: Actual, s	Report source
1	*Atlas* BECO	128.90	128.06	Cape Kennedy
2	*Atlas* booster engine jettison	131.90	131.76	Cape Kennedy
3	Start *Agena* secondary timer	271.85	272.36	Cape Kennedy
4	*Atlas* SECO	287.90	288.56	Cape Kennedy
5	Start *Agena* primary timer	291.80	296.36	Cape Kennedy
6	*Atlas* VECO	308.10	308.06	Cape Kennedy
7	Shroud separation	310.50	310.26	Cape Kennedy
8	*Atlas–Agena* separation	312.50	312.46	Cape Kennedy
9	*Agena* 1st ignition	365.95	370.46	Cape Kennedy
10	*Agena* 1st cutoff	517.59	523.46	Antigua
11	*Agena* 2nd ignition	1880.00	1880.66	RIS *Coastal Crusader*
12	*Agena* 2nd cutoff	1966.55	1967.66	RIS *Coastal Crusader*
13	*Agena*–spacecraft separation	2132.85	2133.16	Pretoria
14	Begin *Agena* yaw	2135.85	2136.46	Pretoria
15	End *Agena* yaw	2195.85	2196.16	Pretoria
16	Begin *Agena* retrofire	2732.85	2732.66	RIS *Sword Knot*
17	End *Agena* retrofire	2748.85	2749.66	RIS *Sword Knot*
	Agena 1st burn duration	151.64	153.00	Cape Kennedy–Antigua
	Agena 2nd burn duration	86.55	87.00	RIS *Coastal Crusader*

Table 46. Time of mark events

Mark event	Time, GMT	Report source
First motion	22:33:00.338	Cape Kennedy
1	22:35:08.40	Cape Kennedy
2	22:35:12.10	Cape Kennedy
3	22:37:32.70	Cape Kennedy
4	22:37:48.90 22:37:49.00	Cape Kennedy Bermuda
5	22:37:56.70 22:37:56.70	Cape Kennedy Bermuda
6	22:38:08.40 22:38.08.50	Cape Kennedy Bermuda
7	22:38:10.60	Cape Kennedy
8	22:38:12.80 22:38:12.70	Cape Kennedy Bermuda
9	22:39:10.80 22:39:11.10	Cape Kennedy Bermuda
10	22:41:43.80 22:41:44.20	Cape Kennedy Bermuda
11	23.04:21.00 23:04:20.80	RIS *Coastal Crusader* Pretoria
12	23:05:28.00 23:05:48.00	RIS *Coastal Crusader* Pretoria
13	23:08:33.50 23.08:33.80	Pretoria Tananarive
14	23:08:36.80 23:08:36.90	Pretoria Tananarive
15	23:09:36.50 23:09:36.90	Pretoria Tananarive
16	23:18:33.00 23:18:33.80 23:18:33.80	Pretoria Tananarive Canarvon
17	23:18-50.00	Pretoria

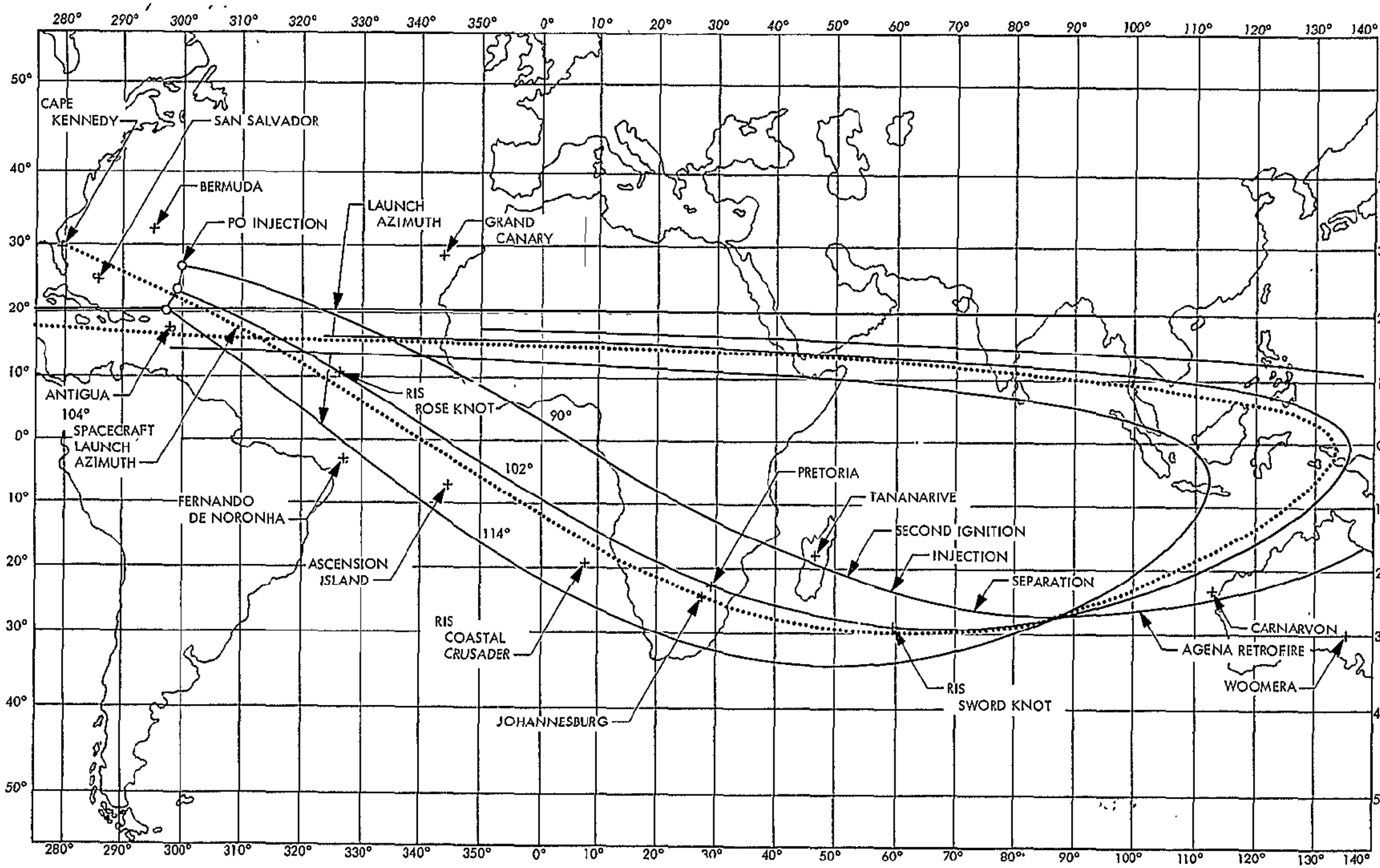

Fig. 78. Mission V near-earth support station location

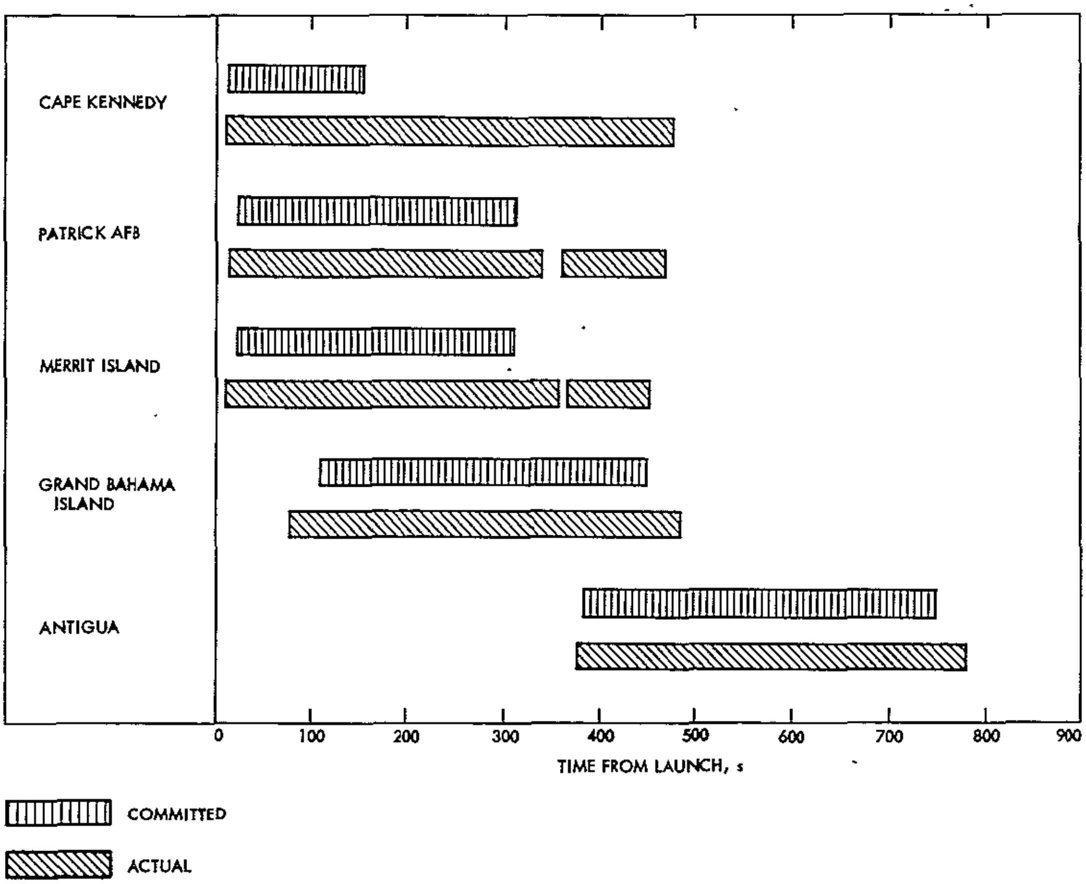

Fig. 79. Mission V AFETR C-band radar metric coverage, launch through Antigua

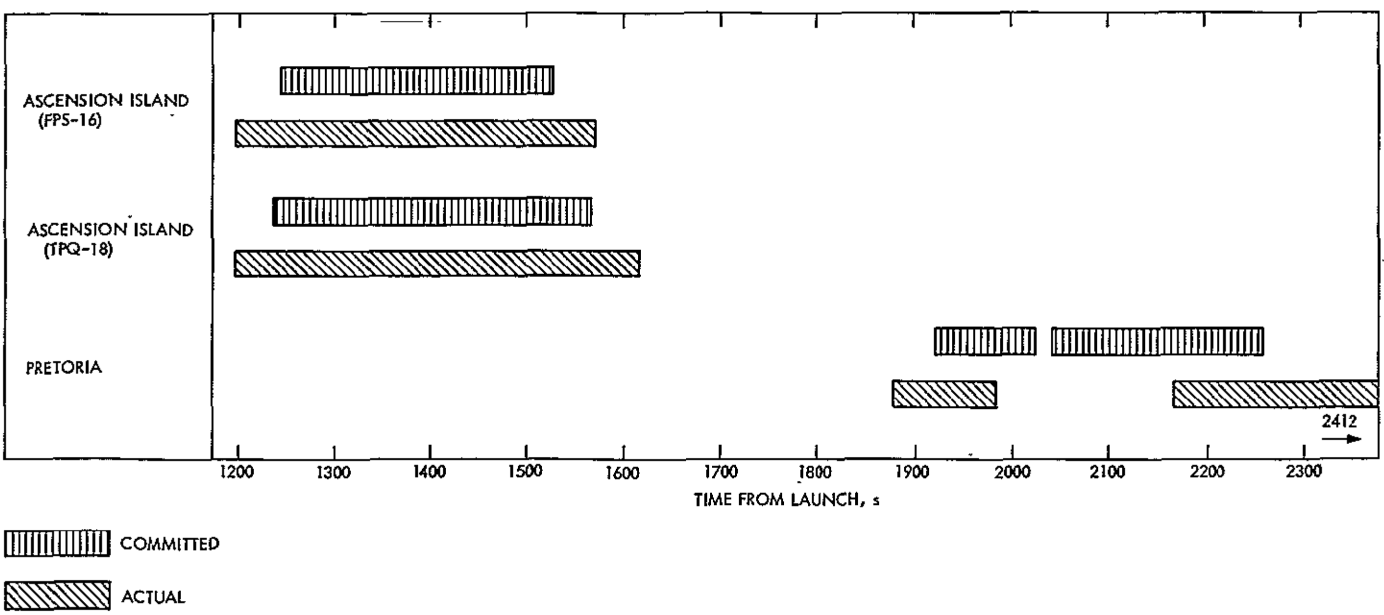

Fig. 80. Mission V AFETR C-band radar metric coverage, Ascension Island through Pretoria

from the downrange sources and switched to DSS 71 for transmission to the SFOF in Pasadena at the times listed in Table 47.

S-band telemetry requirements were met with the exception of the RIS *Sword Knot*. The ship reported very low signal strength and was unable to achieve receiver phase lock. The Pretoria interval extended approximately 190 s beyond its expected termination and provided a 57 s overlap into the RIS *Sword Knot* commitment.

3. *RTCS data processing.* Computations performed by the RTCS are listed in Table 48. All computations were successfully run on time, including a third, unscheduled

Table 47. *Agena* Channel F spacecraft telemetry received at DSS 71 for retransmission to the SFOF

Station	From, GMT	To, GMT	Usable data, %
Tel-4	Liftoff	22:36:00	100.0
Grand Bahama Island	22:36.00	22:40:00	90.9
Antigua	22:40:00	22.46:01	81.3
RIS *Rose Knot*	22:46.16	22:53:08	76.5
Ascension Island	22:53:08	22:59:26	87.5
RIS *Coastal Crusader*	22:59:26	23:04:04	61.5
Pretoria[a]	23:04:04	23;08:34	100.0
Average			85.4

[a]*Agena* burn calibrations occurred in this interval.

Table 48. AFETR Real-Time Computer System performance

Orbit	Epoch, s	Computing time, s	Data source	Quality
Agena–spacecraft parking orbit	$L + 534$	$L + 840$	Antigua	Good
Predicted *Agena*–spacecraft transfer orbit	$L + 1972$	$L + 1260$	Antigua plus nominal 2nd burn	Good
Actual *Agena*–spacecraft transfer orbit	$L + 1970$	$L + 3360$	Pretoria	Fair
Agena post retro orbit	$L + 2717$	$L + 4220$	Carnarvon	Good
Actual spacecraft transfer orbit 1	$L + 3130$	$L + 5760$	DSS 41 (25 min)	Good
Actual spacecraft transfer orbit 2	$L + 3130$	$L + 7560$	DSS 41 (30 min)	Good

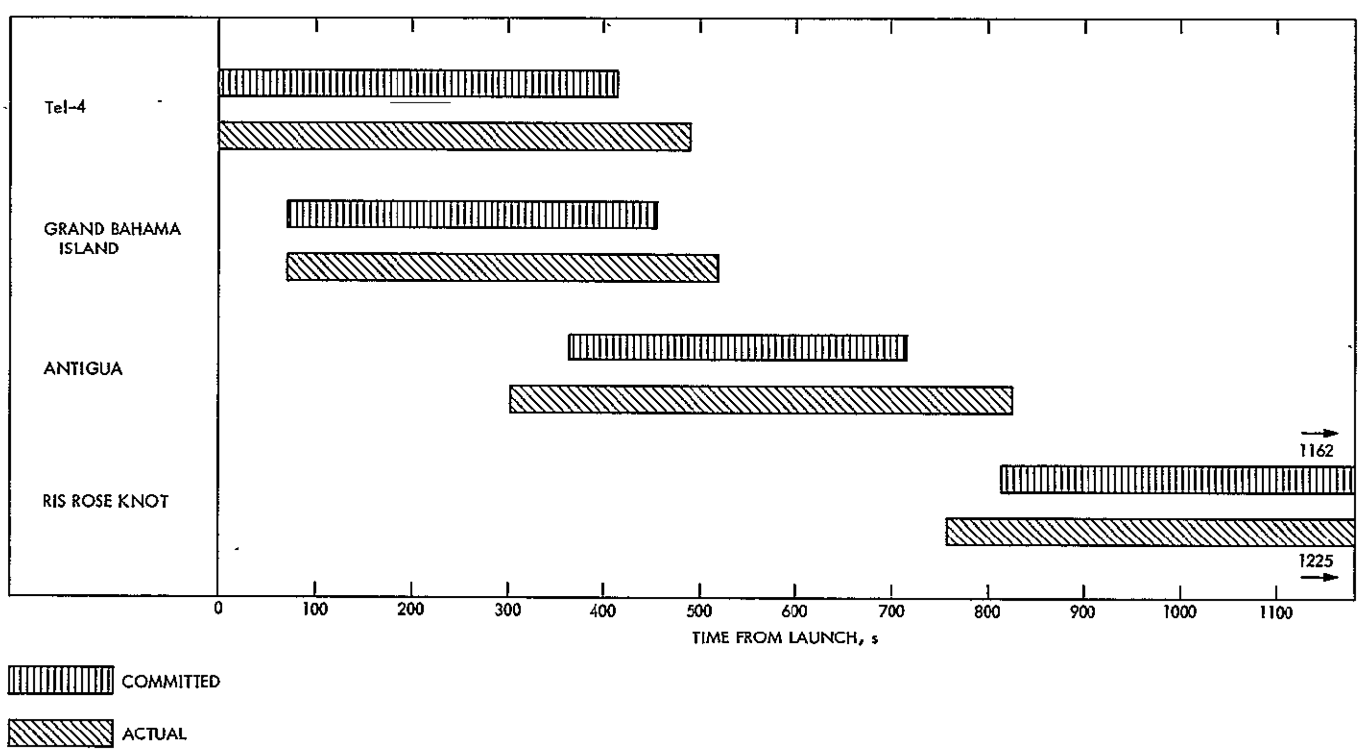

Fig. 81. Mission V AFETR VHF telemetry coverage, launch through RIS *Rose Knot*

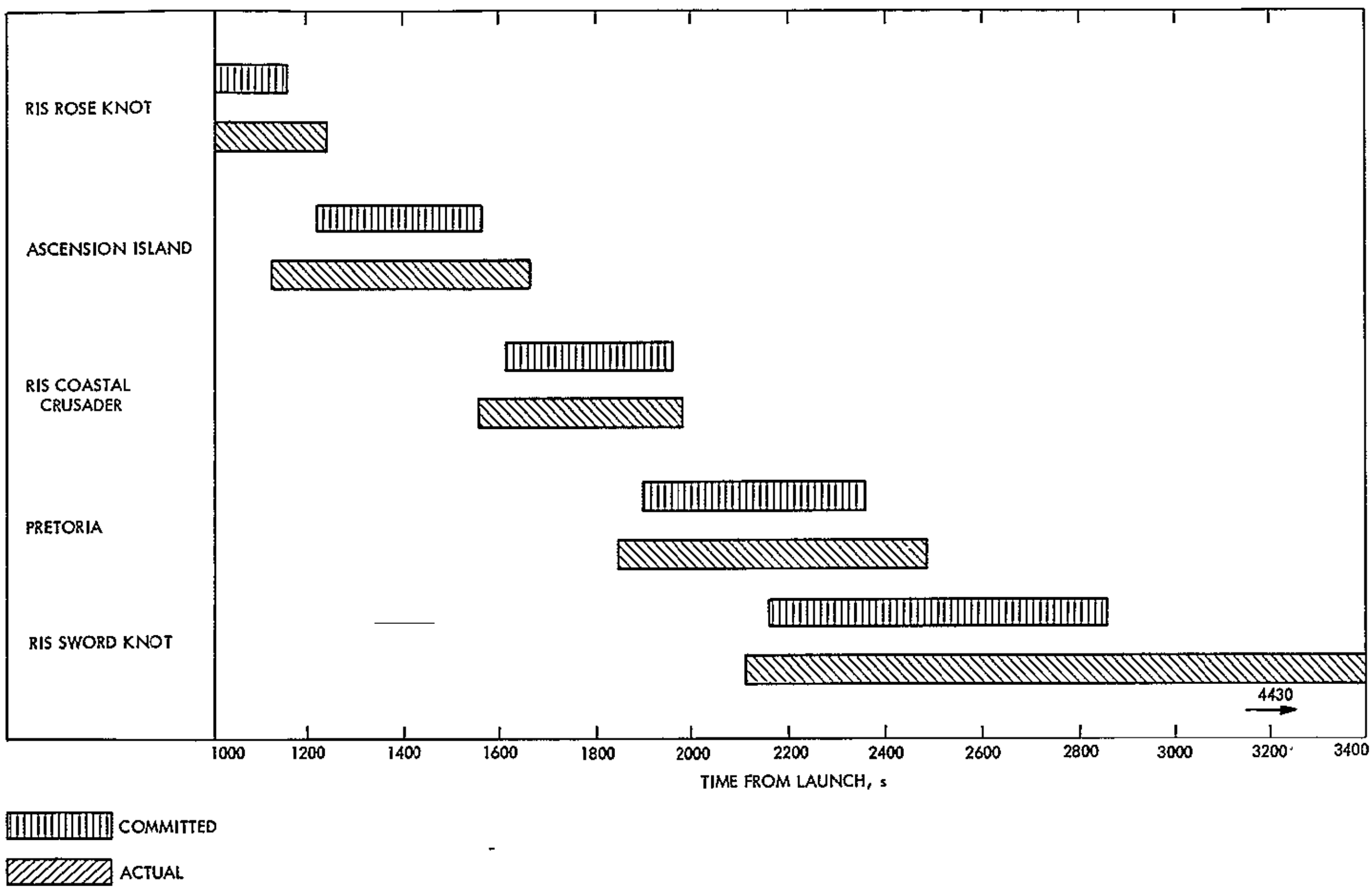

Fig. 82. Mission V AFETR VHF telemetry coverage, RIS *Rose Knot* through RIS *Sword Knot*

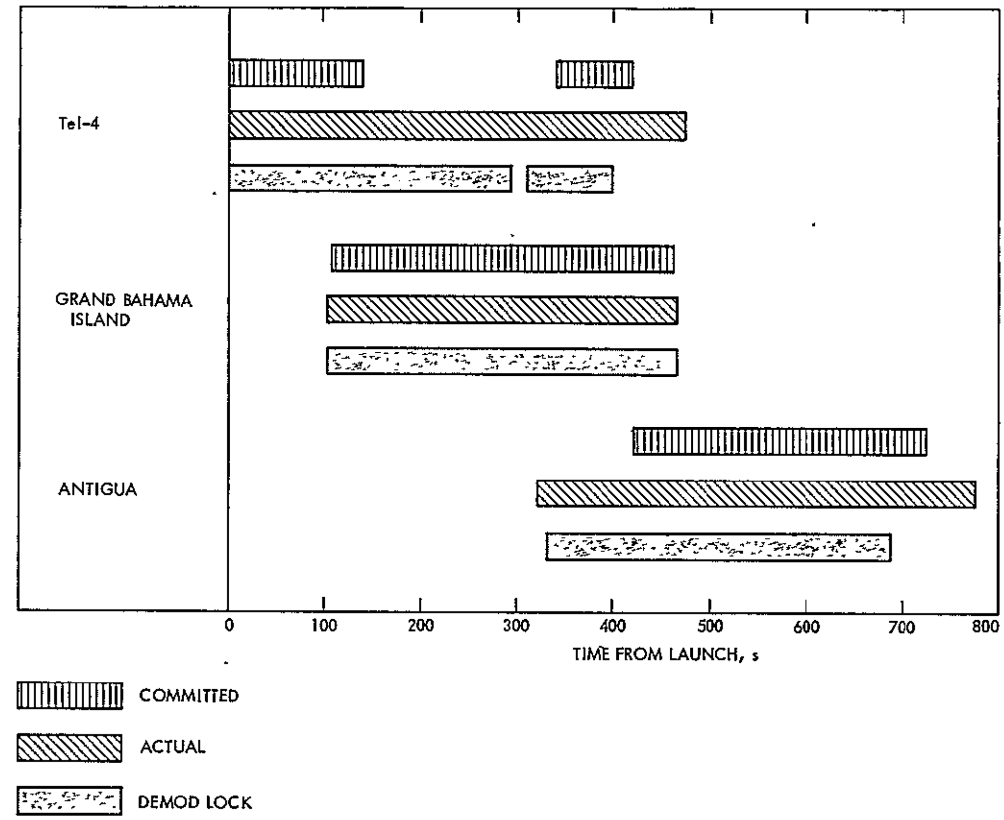

Fig. 83. Mission V AFETR S-band telemetry coverage, launch through Antigua

actual transfer orbit based on DSN metric data. This orbit was also mapped to lunar encounter. Based on these orbits and the first DSN orbit, the flight path was judged to be nominal. Confidence in the normalcy of the data was based on the following:

(1) ODs were available from two independent computer facilities.

(2) Metric data were acquired from two independent facilities.

(3) Both C-band and S-band data were used in the computations.

C. MSFN Performance

1. VHF telemetry and C-band metric data. Committed versus actual VHF telemetry and C-band metric coverage are shown in Figs. 85 and 86.

Bermuda met all support commitments except for the loss of Channel F VHF spacecraft data. The loss was attributed to an operator error that left a switch unactivated during the first 60 s after acquisition.

Tananarive radar was late in acquiring. Although contact was made, the acquisition was not sufficiently accurate to allow radar lock-on until point of closest approach. A failure in the station timing system invalidated what metric data was obtained.

Carnarvon radar, was declared not operationally ready because of power supply and servo problems, but it was still able to provide useable metric data during its coverage period. The 984 s data loss appearing in Fig. 86 was attributed to vehicle aspect angle. Although not committed for telemetry, Carnarvon was able to provide continuous coverage during the view period.

2. Data processing and display. The GSFC Data Operations Branch received all AFETR downrange metric data, generated and transmitted nominal antenna pointing data and real-time acquisition messages for MSFN stations. All required computer support was provided. Low-speed metric data from Tananarive were not recognized by the computer because of an incorrect time tag resulting from the failure of the station's timing system.

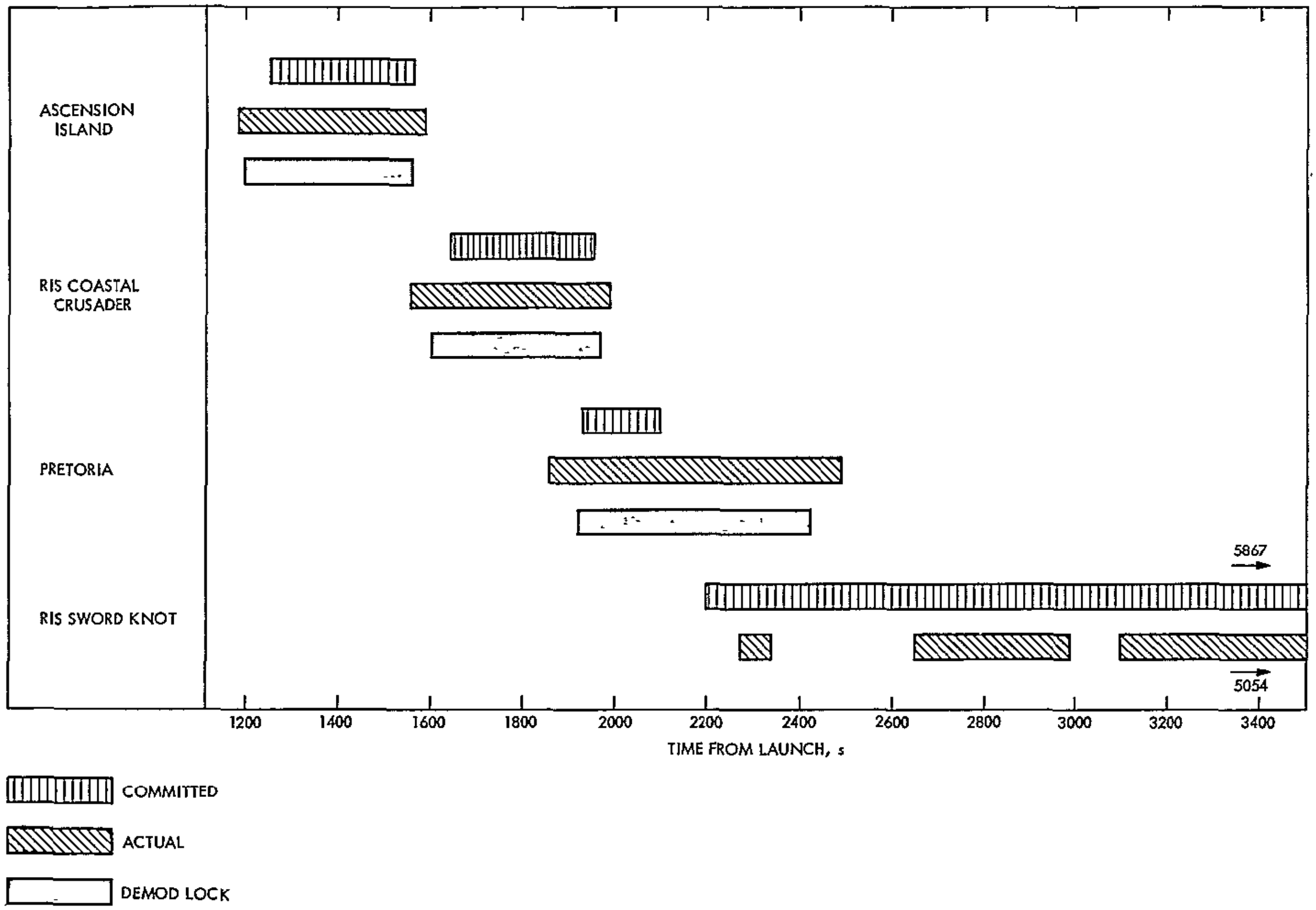

Fig. 84. Mission V AFETR S-band telemetry coverage, Ascension Island through RIS *Sword Knot*

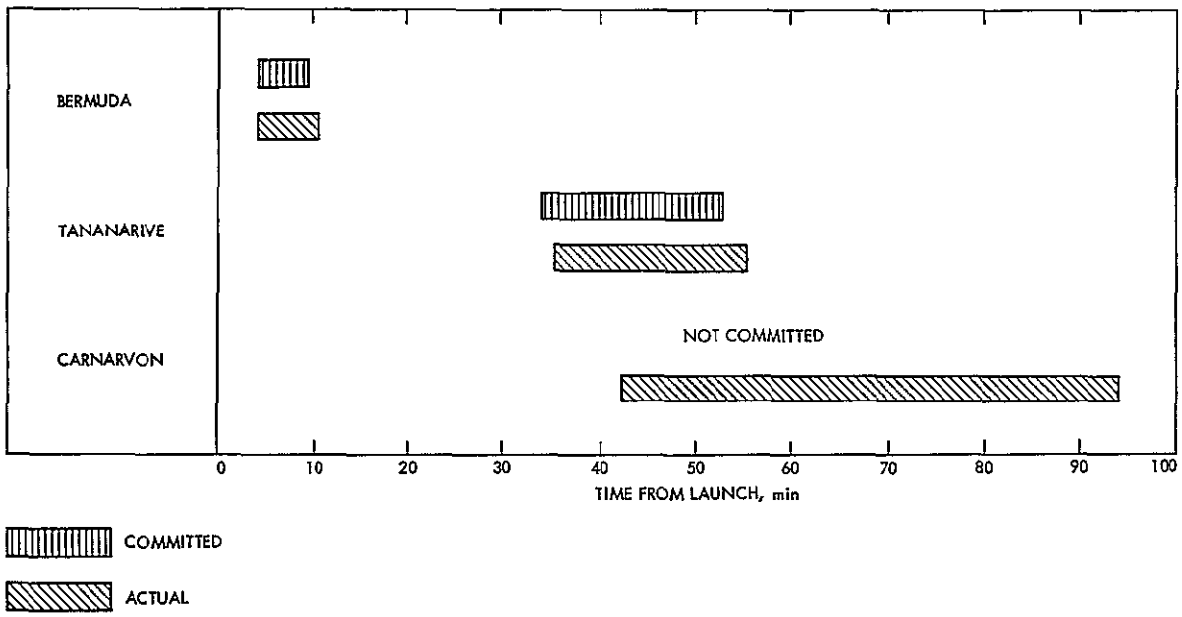

Fig. 85. Mission V MSFN VHF telemetry coverage

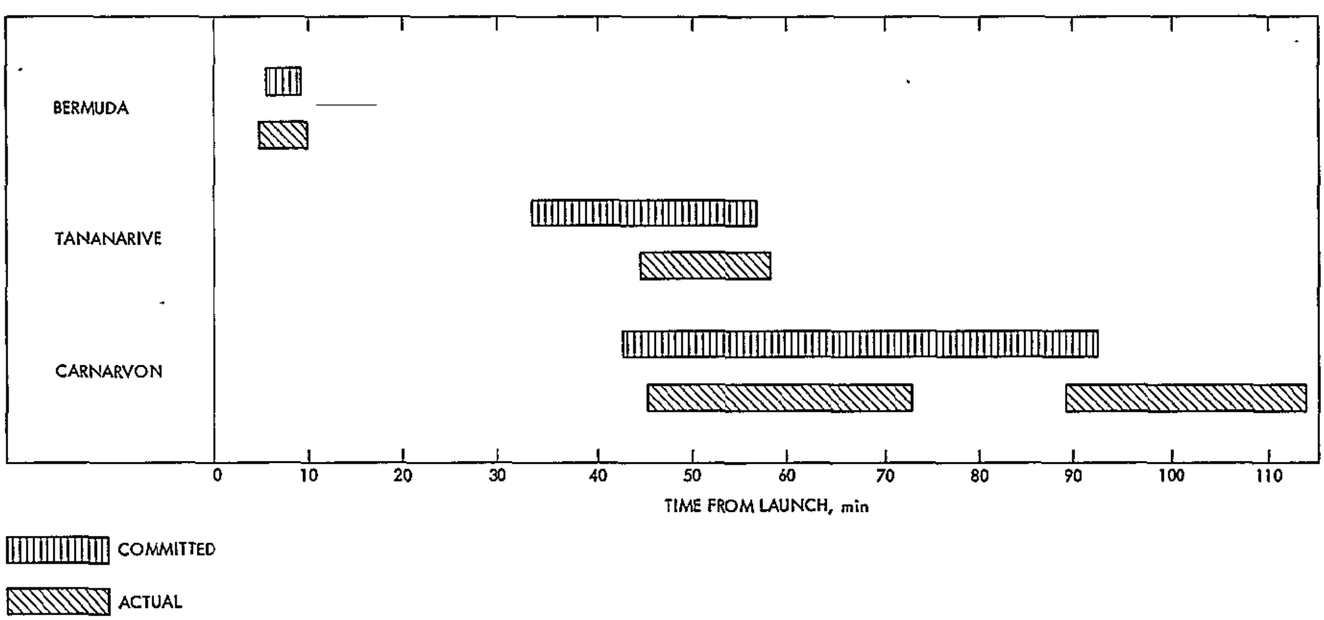

Fig. 86. Mission V C-band radar metric coverage

D. Ground Communications

NASCOM performance during the near-earth phase met all Class I communications support requirements. Voice and teletype communications with DSS 51 were plagued with numerous outages immediately prior to liftoff due to poor HF radio propagation conditions. A teletype circuit was patched through AFETR/COMSAT facilities and used extensively during the minus count and after liftoff. Both DSS 51 voice circuits were lost approximately 2.5 h after liftoff and were rerouted via AFETR/COMSAT facilities with very satisfactory results.

Table 49. Mission V early orbit determination results

Orbit	B • TT, km	B • RT, km	Time of closest approach, GMT
0. Targeted aiming point from targeting spec.	−506	5,093	16.38.00[a]
00. Desired aiming point for polar orbit mission	391	5,725	16:37.37[a]
000. Final aiming point for actual trajectory	375	5,700	17:10:00
1. 1st AFETR orbit based on Pretoria (FPS-16) data	9,054	2,906	19:01:44
2. DSN orbit 1101 based on Pretoria (FPS-16) data	—	—	—
3. AFETR post retro orbit based on Carnarvon tracking data	30,968	524	22:31:54
4. 2nd AFETR orbit based on DSS 41—tracking data	6,605	1,687	18:28:46
5. DSN Orbit 1103 based on 30 s of Pretoria (FPS-16) tracking data, and 40 min of DSS 41 tracking data	6,805	3,516	18:27:07
6. 3rd AFETR orbit based on DSS 41 tracking data	6,569	2,683	18:27:53
7. Project orbit 1202 based on 24 min of DSS 41 tracking data	6,128	3,535	18:25:43
8. DSN orbit 1105 based on 1 h of DSS 41 tracking data	6,322	3,300	18:26:25
9. DSN orbit 1107 based on 2 h and 20 min of DSS 41 doppler data only	6,606	2,997	18.24:58
10. Project orbit 1210 based on 6.5 h of DSS 41, 7 h of DSS 62, and 2 h of DSS 12 doppler and ranging data	6,883	3,481	18:28:05
11. Project orbit 1099 based on 2 passes of DSS 41, one pass of DSS 62, and one pass of DSS 12 data, a post flight orbit evaluation	6,888	3,478	18:28:06

[a]For 102 deg launch azimuth.

Tel-4, Cape Kennedy, was unable to maintain lock-on data received from Bermuda and Tananarive because of voice/data level problems between GSFC and Tel-4.

E. DSN Processing of Near-Earth Metric Data

DSN metric data requirements placed on the AFETR and MSFN called for the transmission of both raw and computed launch vehicle metric data from the RTCS to the SFOF for computation by the DSN FPAC group. Figures 87 and 88 and Table 49 provide a summary of the early orbit determination results computed by both the RTCS and the DSN FPAC group. All requirements were successfully fulfilled with the exception of an orbit based on Pretoria data; only six points of good Pretoria data were available (Orbit 1101) which was insufficient for determining an orbit.

IV. Deep Space Operations and Performance Summary

A. DSN Performance

DSN performance in support of *Lunar Orbiter* V was within Project requirements. The DSN supplied approximately 918 h of computer support and 752 h of DSIF tracking support. This compares with 852 computer hours and 993 tracking hours provided during Mission IV.

After completion of the photographic phase, a number of interesting experiments were conducted. Among these were a spacecraft voice relay experiment conducted by LRC, a convolutional coding experiment conducted by JPL, and a bistatic radar experiment conducted by Stanford University and JPL. Final tests of the *Apollo* GOSS Navigation Qualification Program were completed during this mission, using the *Lunar Orbiter* V spacecraft.

The SFOF 7044/7094 computer string communications error which resulted in frequent computer restarts during the four previous missions was corrected for Mission V, greatly reducing the number of restarts. The problem was finally traced to a computer wiring error which was "exercised" with the *Lunar Orbiter* software. There were a disproportionate number of DSIF equipment failures during Mission V; a possible factor may have been equipment wearout since Mission V took place toward the end of a long and very concentrated high-activity period for the DSIF. Another possibility was improved failure reporting.

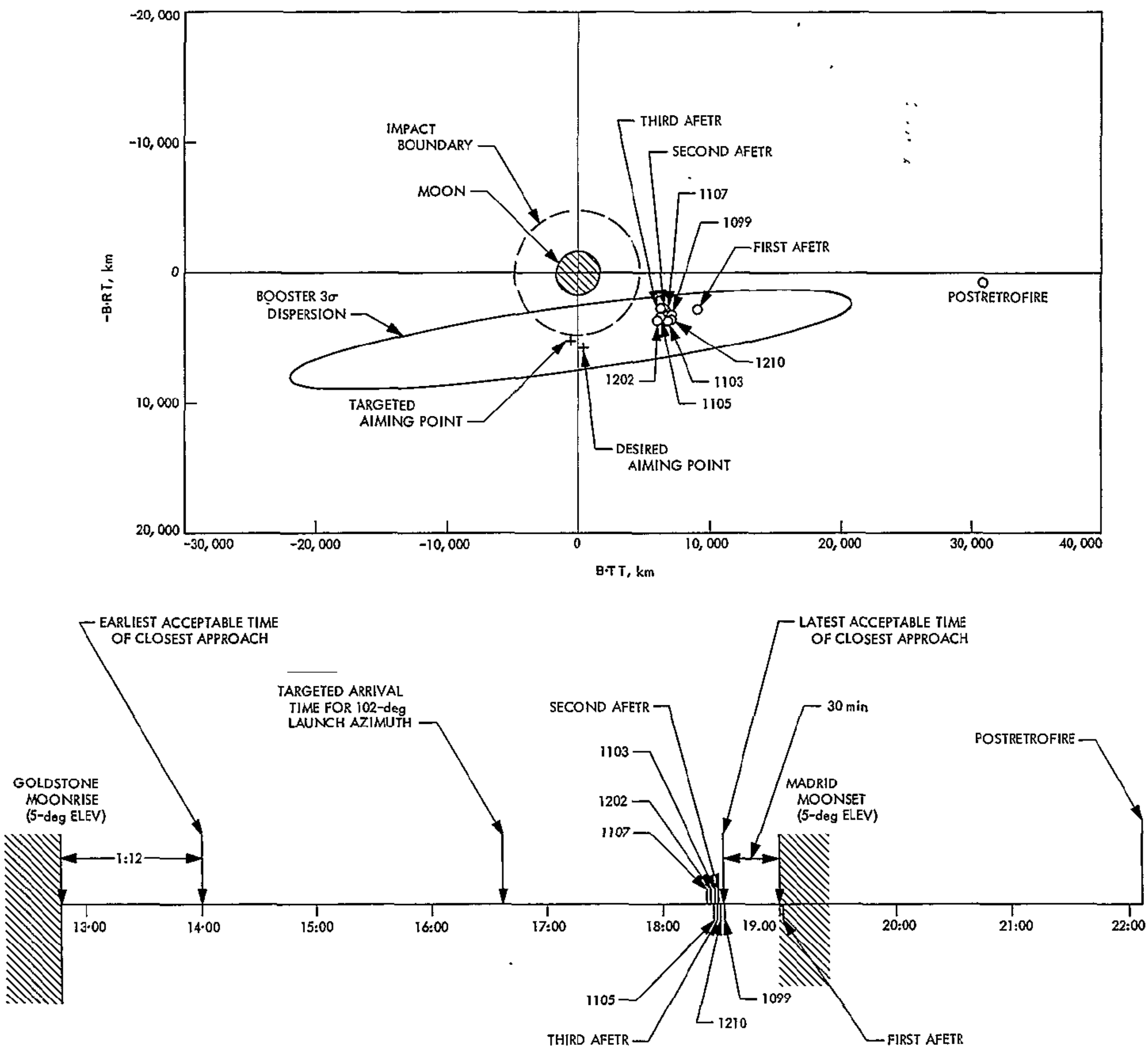

Fig. 87. Mission V early orbit determination B-plane map

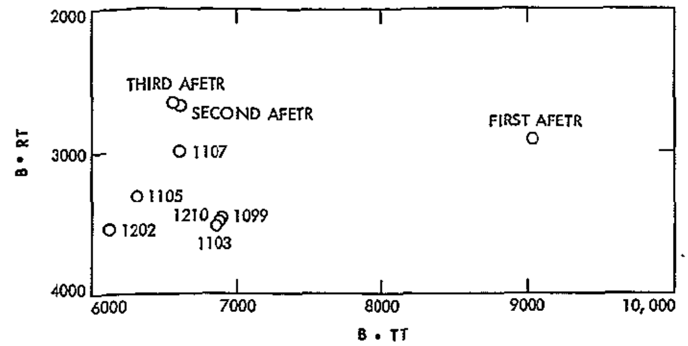

Fig. 88. Mission V early orbit determination results

B. DSIF Performance

1. Overall performance. DSIF performance during Mission V was again very satisfactory. The commitment was for a maximum of 793 h of tracking (31 h/day) based on a 28-day photographic mission. The DSIF tracked a total of 752 h or 94.88% of the maximum commitment. Stations supporting the mission were Deep Space Stations 11, 12, 41, 51, 62, and 71. DSS 11 was used as a backup to DSS 12 to provide a command capability to the spacecraft in the event of a nonstandard earth-orbit mission. The acquisition aid antenna at DSS 11 was to be used to acquire the spacecraft and command it into a higher earth orbit. DSS 72 was utilized on a training basis to track the spacecraft during the launch phase.

Over 48 h of ranging data were taken during the mission. During ranging operations, 22 DSIF station time correlation measurements were made. A summary of the total coverage provided during both the photographic and extended mission phases is listed in Table 50.

2. Flight summary

a. Launch and acquisition phase. After liftoff, DSS 71 tracked the spacecraft manually for 7 min, experiencing short outages, until one-way lock was lost at the horizon. DSS 72 tracked the spacecraft as a training exercise for approximately 6 min.

Table 50. Total DSIF coverage summary for Mission V photographic and extended mission phases

DSS	Two-way tracking, h	Three-way tracking, h	Total tracking, h	Ranging, h	Time correlation, h
12	185.82	57.61	243.44	17.81	1.09
41	215.49	39.05	254.54	12.91	0.56
51	—	4.53	4.53	—	—
62	194.59	55.06	249.66	17.76	0.52
Totals	595.90	156.25	752.17	48.48	2.17

DSS 51 acquired the spacecraft in one-way lock at 25:07:00 GMT and tracked for a total of 4.5 min. Because of the short view period and high angular rates, the station's commitment was for one-way, quick-look, S-band telemetry on a best efforts basis only.

DSS 41 was the initial acquisition station for the mission and was in one-way lock on the acquisition aid antenna at 23:10:11; two-way lock on the antenna main beam was confirmed at 23:23:23 GMT. Acquisition was normal and followed standard acquisition procedures. Average signal strength during the pass was −118.3 dBmW.

b. Transit and lunar phase. The midcourse maneuver was performed at 06:00 GMT on August 3. DSS 41 was prime for the maneuver with DSS 62 acting as backup.

Approximately 2 h prior to injection into lunar orbit on August 5, DSS 12 turned off ranging modulation and immediately lost two-way lock. The two-way configuration was regained approximately 5 min later. The anomaly was attributed to a spacecraft malfunction. As a precaution, ranging was discontinued until completion of the photographic mission.

Injection into lunar orbit occurred at 16:57 on August 5. The initial orbit adjustment was accomplished at 08:43 GMT August 9. Final photo readout was completed on August 27 and the extended mission portion of Mission V was initiated at 02:00 GMT, August 28.

c. Signal levels. Received signal levels during the mission were typical of received signal levels recorded during the four previous missions. Signal strength for all missions was from 3 to 4 dB above predictions.

d. Station anomalies. Anomalies and their causes and effects on the mission are listed in Table 51. Only two anomalies had any significant impact: These were (1) the loss of two-way lock when ranging modulation was turned off prior to orbit injection on August 5, and (2) severe interference during video readout on August 9. A prime suspect was the station test transponder which was undergoing repair at that time and may have been radiating power. Subsequent testing, however, eliminated the transponder as a source.

Table 51. Mission V summary of DSIF anomalies

DSS	Day	Time, h:m GMT	Anomaly	Probable cause	Remedy	Effect on mission	Comment
51	213	23:11	TDH printout failed	Unknown	Attempt to repair	None	Random failure
41	214	01:44	Receiver No. 2 failed	Bad amplifier	Replaced amplifier	None	Random failure
62	214	04:00	TDH data lost	Broken tape	Replaced tape	9 min of TDH data lost	Random failure
51	214	09:34	Unable to run system noise temperature during post-calibration	Empty nitrogen load	Recharged load	None	Human error
12	214	12:05	Power output magnetron amplifier off. Transmitter for Analog Instrumentation Subsystem recording failed	Bad magnetron amplifier	Replaced magnetron amplifier	None	Random failure
12	214	13:54	Rubidium standard No. 2 failed	Bad power switch from running time panel to rubidium oscillator	Switched to Knight crystal oscillator	None	Random failure
62	214	03:40	Rubidium standard No. 2 failed		Switched to Knight crystal oscillator No. 1	None	Random failure
62	215	10:17	Antenna runaway	Faulty power supply	Attempted to recover control of antenna	45 s of tracking time lost	Random failure
41	215	02:05	Transmitter turned off accidentally when turning off ranging mode.	The wrong switch thrown	Reset transmitter	22 min of data lost	Proposed ECR to prevent this
62	215	02:18	Beta TCP failed	Photo reader inoperable	Tape reader rocker arm readjusted	None	Random failure
12	217	15:45	Uplink lock lost after ranging turned off in spacecraft	Unknown	Attempted to reacquire	Approximately 5 min of tracking time lost	Ranging discontinued until completion of photo mission
12	218	15:30	Uplink lost	Incorrect transfer procedure	After problem was realized correct procedure initiated	22 min of tracking time lost	Human error
62	218	15:37	Receiver 1 failed	Acquisition potentiometer failed	Switched to Receiver No. 2	None	Random failure

Table 51 (contd)

DSS	Day	Time, h:m GMT	Anomaly	Probable cause	Remedy	Effect on mission	Comment
41	218	23:30	Exciter tracking filter failed	Mechanical linkage of exciter VCO acquisition pot loose	Drive train clutch adjusted	None	Random failure
62	219	15:52	GRE power failure	Unknown	Attempted to restore power	Power off 1 min	
12	219	23:30	FR 900 failed	Motor drive amplifier failed	Replaced drive amplifier	None, occurred during playback	Random failure
41	219	23:15	TDH punch errors	Intermittent problem	Resealed format board	None	Random failure
12	220	14:00	TCP beta computer failed	Unknown	Attempted to repair	None backup equipment	Random failure
41	221	05:00	Incorrect TDH printout in format 07	Open	Informed SDA Group	None because SDA was informed of error	
12	221	11:00	Test transponder No. 1 in MDE failed	Auxiliary oscillator failed	Switched to two-way lock on test transponder	None at time of failure. When under repair, suspected of interference during video readout. Later tests could not verify interference.	Random failure
12	222	00:13	Antenna oscillation in hour angle	Low speed integrator failed	Replaced integrater	None	Random failure
12	222	20:32	Transmitter tripped off	Door closing on exchanger tripped relay	Reset relay	15 min of transmitting time lost	Human error
41	223	11:51	APS failed	Program failed to sample predict tape	Switched to aided track	None	Intermittent problem
12	223	15:00	Receiver No. 1 failed	MGC potentiometer failed	Replaced MGC potentiometer	None	Random failure
12	226	19:59	Rubidium No. 1 failed	Unknown	Removed and replaced	None	Random failure
12	226	19:59	PC-141 clock power supply failed	Diode and transistor failed	Removed and troubleshot	None	Random failure
12	227	00:53	Receiver No. 1 failed	Muffin fan on isolation-amplifiers failed	Replaced muffin fan; switched to Receiver No. 2	None	Random failure
12	227	04:35	Transmitter failed	Beam supply cable shorted to ground	Transferred, on an emergency basis, to DSS 41	24 min of tracking time lost	Cable insulation broke down

Table 51 (contd)

DSS	Day	Time, h:m GMT	Anomaly	Probable cause	Remedy	Effect on mission	Comment
41	227	08:25	Tape on FR 900 jumped out of track	Locking hubs loosened	Tightened locking hubs	7 min of FR 900 data lost	Possible human error
62	228	17:34	Transmitter tripped off	Arc detector circuit activated and removed beam and drive	Reset arc detector	5 min of data time lost	Random failure
12	230	08:37	TDH outputting 7's instead of 0's in ranging column	Blown fuse	Replaced fuse	None	Random failure
12	230	08.26	Low and fluctuating signals from 08:50. Lowest signal noted −158 dBmW	Undetermined	Checked station receivers	DSS 12 data bad for 24 min	None
12	230	18:13	Telemetry and Command Data handling backup computer failed	Bad clear switch	Replaced clear switch	None	Random failure
12	231	05:40	FR 1400 recorder 2-B failed	Shorted transistor in 28V regulator	Replaced transistor	One min of backup data lost	Random failure
12	232	03.00	Servo failure	Low speed tachometer belt failed	Belt replaced	None	Random failure
62	232	21:27	FR 900 recorder failed	Tape poorly packed and jammed	Cleared tape jam	97 s of recording time lost	Random failure
41	233	12:50	No voice on FR 1400 (track 5) or FR 900 recorders from 1:56	Incorrect communication configuration	Corrected communication configuration	54 min of voice data lost	Human error
62	234	06:50	APS failed	Drive tape not read by computer	Reloaded APS program	5 minutes of tracking time lost	Random failure
12	235	04:33	APS failed	±300 V supply low	Adjusted supply	None	Random failure
12	235	09:08	Uplink lock lost	Synthesizer tracking filter loop lost lock due to bad power supply	Replaced power supply	Two-way track transferred to DSS 41 at 10:30 instead of 13:00 as planned	Random failure
62	235	20:30	Transmitter failed during precalibration	Defective HV cable insulation	Moved cable away from nearby metallic objects	None	Random failure

Table 51 (contd)

DSS	Day	Time, h:m GMT	Anomaly	Probable cause	Remedy	Effect on mission	Comment
41	237	12:45	Test transmitter in collimation tower failed	Not reported	Removed test transmitter for repair; replaced with spare	Station unable to make prepass AGC calibrations	Random failure
12	237	16:50	Dec channel servo failure	DC meter failed	Replaced meter	None	Did not affect track
41	238	17:03	FR 900 recorder failed	Open	Changed head and motor drive amp; did not correct trouble	None	Random failure
62	239	04:00	Transmitter off	Arc detector activated	Reset arc detector	None	Random failure

3. *DSIF operations*

a. Multi-spacecraft tracking. Operational procedures for Mission V were essentially the same used for Mission IV with respect to tracking and station transfers at offset (biased) frequencies. Acquisition procedures were slightly refined to accommodate lunar occultations and the proximity of *Lunar Orbiter II* and *III* frequencies so that only the desired spacecraft would be acquired.

b. Command procedures. Command procedures were normal and not affected by the offset frequency operations. Command static phase error limits were the same as for Mission IV (±8.5 deg).

4. *Tracking data analysis*

a. Performance summary. The DSIF SDA Group provided around-the-clock support from launch through the end of the photographic mission, and on a one-shift-per-day basis until completion of photo readout. The Group's function was to provide liaison and coordination between the deep space stations where the tracking data originate and the DSN and Project FPAC groups who are the data users. SDA Group activities included tracking data monitoring and data quality assessment for the FPAC Orbit Determination Group, frequency inputs to the ODP, acquisition predictions to the deep space stations, and consultation with the DSIF Operations Engineering Group on the solutions to problems.

The performance of the DSIF tracking data system during Mission V was satisfactory. There were no major data outages and good data averaged better than 90% of the data received. Considering the difficulties associated with acquiring the spacecraft at an offset frequency during station handover, there were very few uplink dropouts.

b. Spacecraft auxiliary oscillator frequency measurements. Normally, DSS 71 performs prelaunch auxiliary oscillator frequency measurements at $T-80$, $T-30$, and $T-6$ minutes. Because of the long, unscheduled, hold due to weather, an additional measurement was requested and was labeled $T-50$. This frequency was inserted in the prelaunch predict set used by DSS 41 for initial acquisition.

c. Predicts generation. In response to an operations directive on August 12, dual predicts were run with both positive and negative offsets so that the appropriate offset would be available for each pass. The procedure was discontinued after 2 days because of limited computer time and too many predicts for the stations to handle. A new procedure was put into effect where only one predict set was run with an offset selected by the SDA Group.

Through the first week of final orbit, predicts degenerated rapidly, with periselenium residuals exceeding 1000 Hz after only one and a half days. This necessitated that predicts be run every day. Discussions between the FPAC Orbit Determination Group and the SDA Group concluded that the problem was the result of a mismatch between the lunar harmonics in the ODP and the PRDL. The condition was compounded by the limited amount of good data being received at the time. Predicts were greatly improved after PRDL was altered to incorporate the ODP harmonic values. It was later determined that the real cause of the predicts degeneration was the existence of the lunar mass concentrations.

d. Tracking data monitoring. Tracking data were backfed to the Goldstone computer facility and processed by the TDM Program. The received data were compared with a set of predicts that were either internally generated or received from the SFOF, and the residuals were computed. The standard deviation of the last five points was calculated and used to determine an estimate of the data noise. The output was transmitted to the SFOF via teletype and printed in tabular form, and also displayed on a 30 × 30-in. XY plotter. During the cislunar phase the residuals showed bias errors of less than 1 Hz and noise errors of less than 0.1 Hz, indicating high-quality data.

Figures 89 through 92 show the result of SDA monitoring of spacecraft velocity maneuvers. The midcourse plot (Fig. 89) describes a nominal midcourse with a doppler change of 427.8 Hz; the predicted change was approximately 430 Hz. The injection maneuver plot (Fig. 90) should show a straight line instead of a step function since the actual maneuver was compared to a predict set containing a nominal burn. The step function results from comparing actual performance to a prediction that does not include a burn. In this instance, the step function was cauesd by the predict set which had already degenerated to large residuals; the set was replaced after the first good orbit determination. The first orbit change plot (Fig. 91) shows a plus 68 Hz doppler change against a predicted change of 69 Hz. The second orbit change plot (Fig. 92) was generated using predicts which included a burn and indicates the actual maneuver as +18 Hz off, which is a fairly good burn.

5. Ranging and time synchronization

a. Ranging operations. Ranging data were taken during the first five days of the photographic mission. On August 5, a spacecraft anomaly was suspected when the uplink was lost immediately after turning off ranging

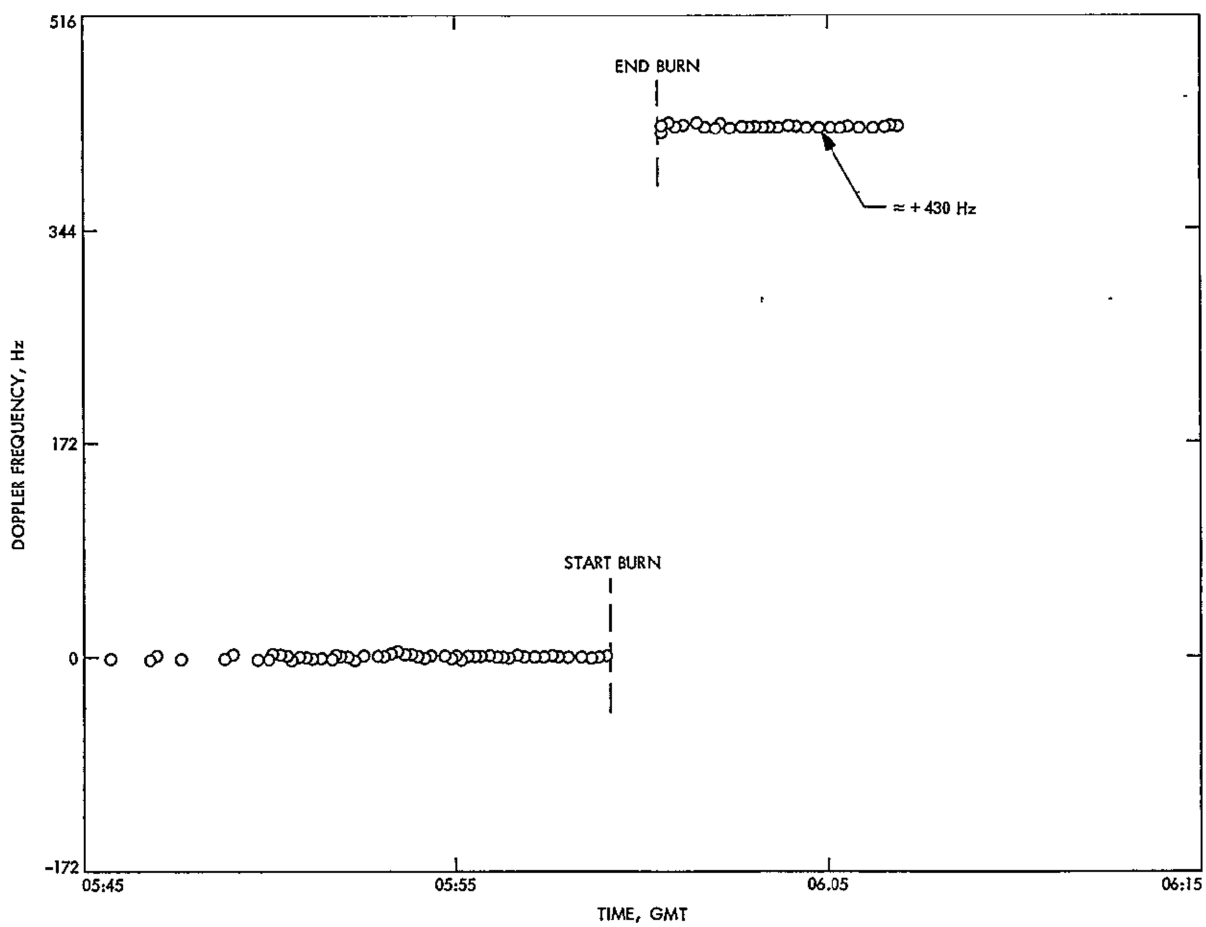

Fig. 89. Mission V midcourse maneuver doppler shift

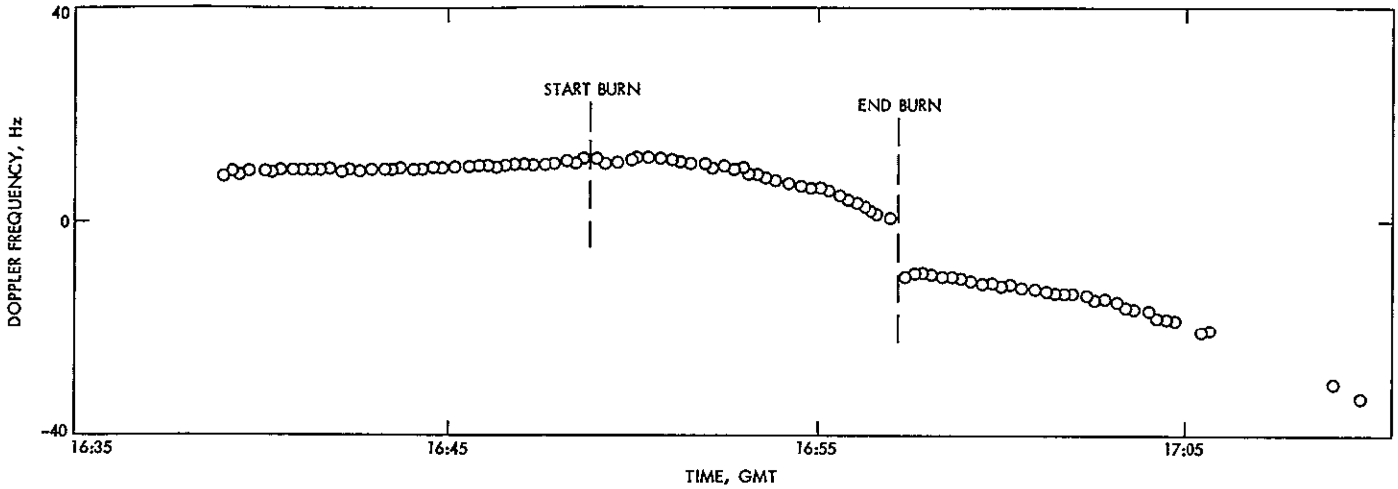

Fig. 90. Mission V orbit injection maneuver doppler shift

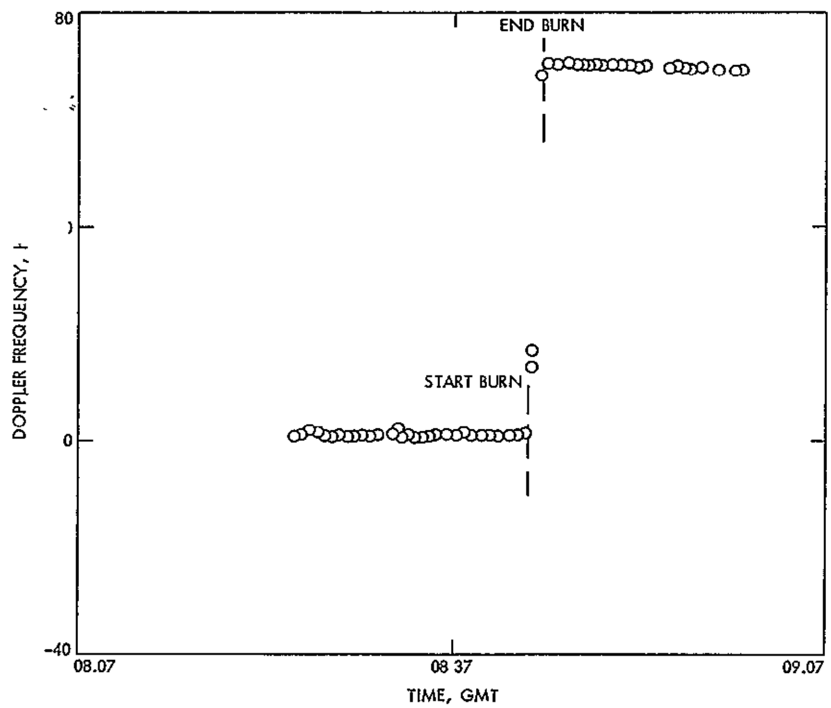

Fig. 91. Mission V first orbit change doppler shift

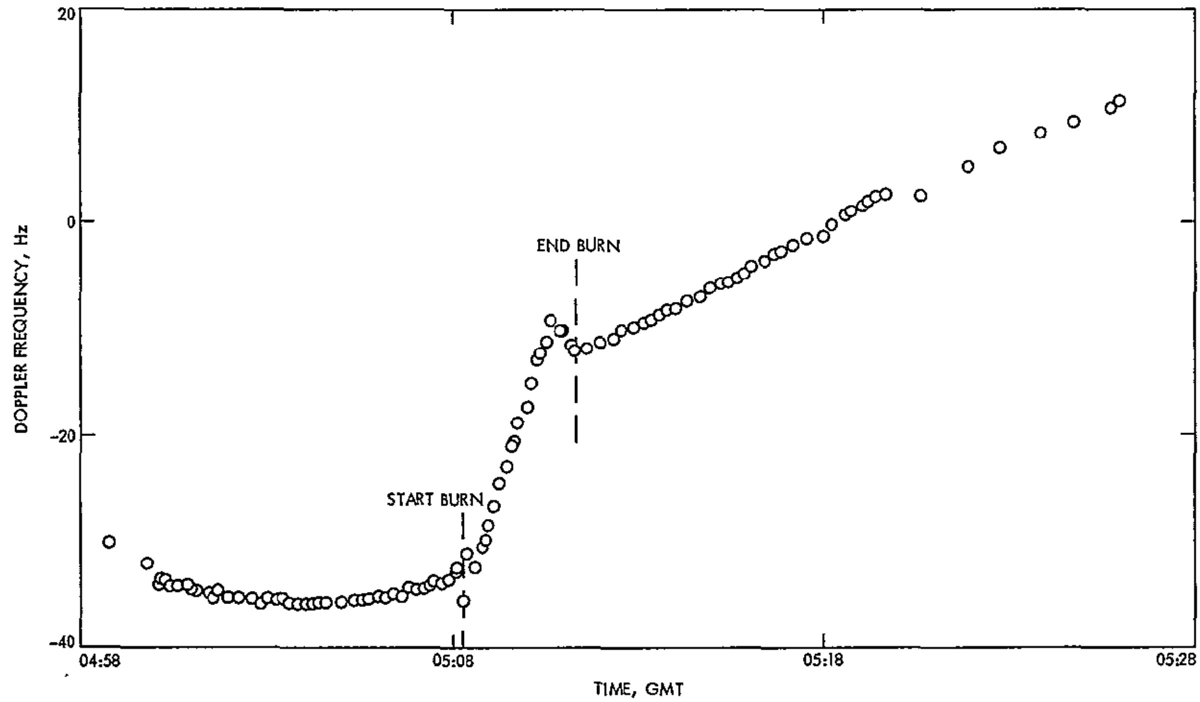

Fig. 92. Mission V second orbit change doppler shift

modulation. As a precaution, ranging operations were terminated until after completion of the photographic mission.

b. Time correlation. Time correlation measurements were made to determine the time offset between the master station clocks at two separate stations during the same time period. The time difference (bias) was inserted into the ODP to update the time tags on the tracking data supplied by each station. The measurements were taken during the period from August 2 through August 4, 1967. The participating stations were DSS 12, DSS 41, and DSS 62. Table 52 lists the actual time difference between the stations. The time is given in GMT and is at the midpoint of the measurements.

C. GCF/NASCOM Performance

GCF/NASCOM performance during Mission V was the most reliable of any of the previous missions. Problems were minimal during all phases of the mission; Goddard circuit restoration support proved to be very satisfactory.

1. High-speed data lines. This portion of the communications system again performed exceptionally well during all tests and mission phases with virtually 100% reliability. The DSS 41 circuit had the lowest reliability with 99.32%. The transmit side of the lines was used during the launch phase to backfeed status information and the command link to the DSIF stations.

2. Teletype circuits. The teletype circuits were also exceptionally reliable. The three prime stations during launch (DSSs 12, 41, 62) showed better than 99% reliability. Of the secondary stations, the weakest circuits were to DSS 51 with 93.51% reliability, a drop of approximately 5% from Mission IV.

3. Voice circuits. The NASCOM voice circuits provided for the *Lunar Orbiter V* Mission and tests performed well within expectations. The DSS 41 voice circuit was the weakest with approximately 99.83% reliability, an improvement of 13% over Mission IV. The other prime stations (DSSs 12 and 62) showed better than 99% reliability during all tests and mission phases.

4. JPL–Goldstone microwave system. The Goldstone–SFOF microwave system operated by the Western Union Company provided excellent communications service with 99.42% reliability, down 0.34% from Mission IV.

D. SFOF Performance

1. Data Processing System. The overall performance of the Data Processing System was the most successful of the five missions. There were no major software or hardware failures during the mission and such minor problems that did occur were random in nature. Mission V was supported with a total of 918 computer hours from August 1 through August 25 (photographic phase).

a. Central computing complex. Occasional comm-error problems between the 7044 input-output processor and the 7094 main processor were again present during Mission V but had no significant effect on the mission and no data were lost. Frequent problems occurred in the 7044 computer that were hardware/software oriented in the 1301 disk file system. Although the problem did not adversely affect *Lunar Orbiter*, it did create a print processing backlog which, at times, delayed output deliveries to the Project users.

b. Software problems. All software problems were of a minor nature, consisting mainly of program problems that necessitated restarts.

c. Hardware problems. In general, hardware performance was reliable. Printer, plotter, cardreader, and other display device malfunctions in the user areas were quickly corrected by maintenance personnel. A drum storage failure in a 7044 computer used by the *Mariner 67* Project resulted in a switch of computer strings which caused a 15-min loss in *Lunar Orbiter* processing time during the switch. There was no data loss, however.

2. *Training and staffing.* Training and staffing for the mission were adequate. A shortage of manpower caused some delays in the delivery of tapes and data to the processing stations. The problem was relieved by additional support from the SFOF Support Group.

3. ***SFOF operations.*** Operational performance was good. Simulation programs performed during the Operational Readiness Tests contributed significantly to the good performance level maintained by SFOF personnel. Scheduling conflicts arose due to the overloading of DSN resources to meet multimission commitments. There were no configuration control or configuration freeze problems during the mission.

Table 52. Mission V DSIF time synchronization measurements

Date Aug. 1967	Time, GMT	Stations		Difference, μs
		DSS	DSS	
2	13:52	12	62	301.58
	13:54	12	62	301:57
	15:46	12	62	301.9
	15 47	12	62	302.08
	15:48	12	62	301.98
	15:49	12	62	302.04
	15:50	12	62	302.07
	15:51	12	62	302.09
	22:27	41	12	162.6
	22:29	41	12	162.54
3	15:33	12	62	357.31
	15:34	12	62	357.23
	15:36	12	62	357.25
	15:42	12	62	357.27
	15:43	12	62	357.21
	22:31	41	12	119.86
4	14:00	12	62	324.39
	14:01	12	62	323.26
	14:02	12	62	329.78
	14:04	12	62	329.03
	14:05	12	62	329.88
	14:09	12	62	323.28
	14:10	12	62	329.99
	15:32	12	62	334.41
	15:33	12	62	334.69
	15:34	12	62	335.13
	15:35	12	62	334.61
	15:36	12	62	335.35
	15:40	12	62	335.65
	15:41	12	62	335.46
	22:13	41	12	224.32
	22:14	41	12	222.78
	22:15	41	12	223.15
	22:16	41	12	223.14
	22:17	41	12	223.11
	22:23	41	12	223.16
	22:24	41	12	223.25
	23:20	41	12	223.29
	23:21	41	12	223.69
	23:22	41	12	223.96
	23:24	41	12	223.54
	23:25	41	12	224.29
	23:29	41	12	223.58
	23:31	41	12	223.81

E. DSN FPAC Performance

The tracking data quality determination function operated very satisfactorily during Mission V; doppler resolver data were obtained at all stations. The noise error due to quantization was virtually eliminated, and a factor of five reduction was seen in the amplitude of the doppler residuals (although the systematic errors in the residuals near pericenter passage were still present).

Acquisition times were comparatively long due to the 300 Hz offset acquisition frequency; this caused a slight loss of data, but had no adverse effect on orbit of the five missions. There were no major software or hardware failures during the mission and such minor problems that did occur were random in nature. Mission V was supported with a total of 918 computer hours from August 1 through August 25 (photographic phase).

a. Central computing complex. Occasional comm-error problems between the 7044 input-output processor and the 7094 main processor were again present during Mission V but had no significant effect on the mission and no data were lost. Frequent problems occurred in the 7044 computer that were hardware/software oriented in the 1301 disk file system. Although the problem did not adversely affect *Lunar Orbiter*, it did create a print processing backlog which, at times, delayed output deliveries to the Project users.

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	15:35	12	62	334.61
	15:36	12	62	335.35
	15:40	12	62	335.65
	15:41	12	62	335.46
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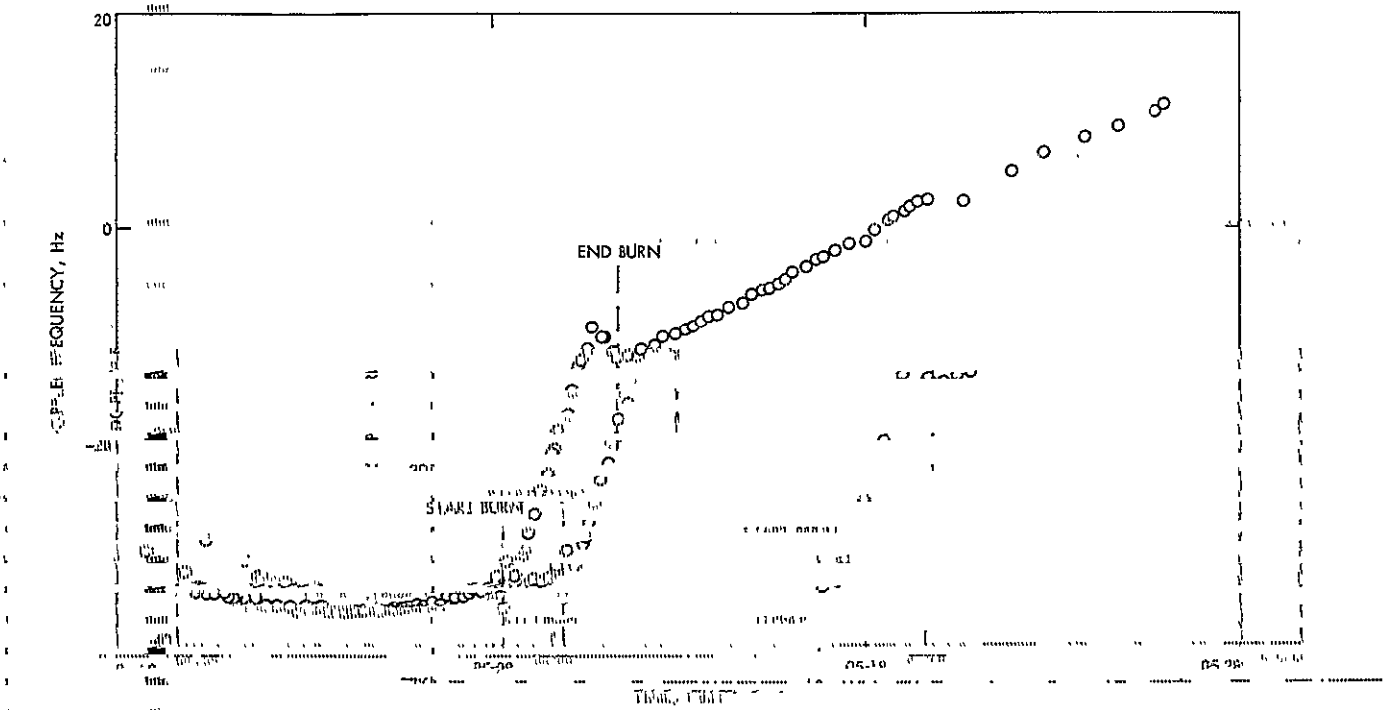

Fig. 92. Mission V second orbit change doppler shift

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5. Ranging and time synchronization

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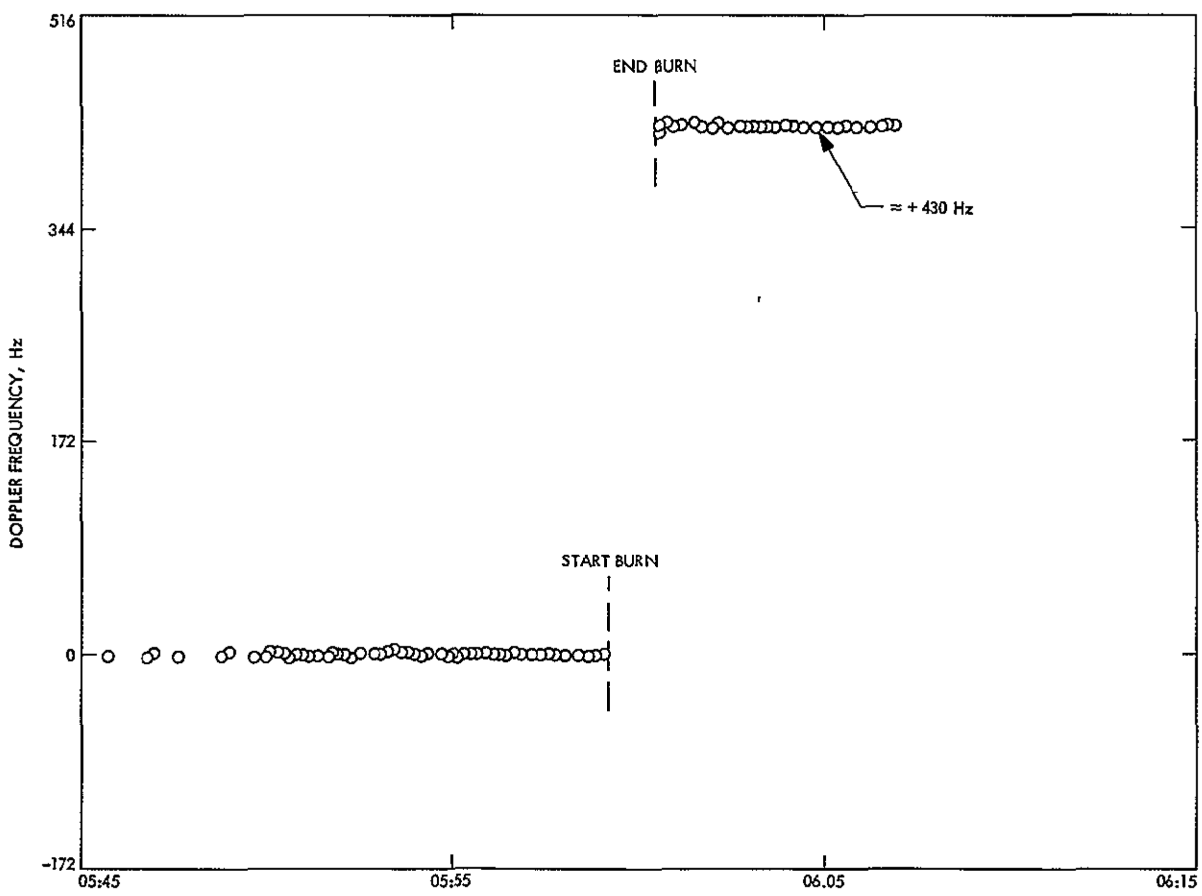

Fig. 89. Mission V midcourse maneuver doppler shift

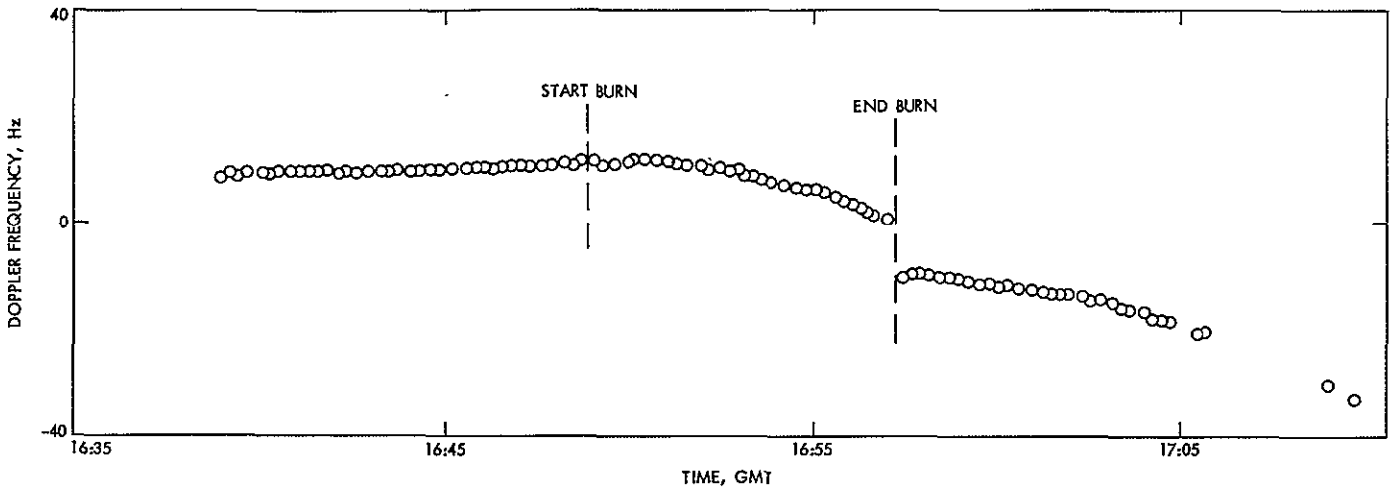

Fig. 90. Mission V orbit injection maneuver doppler shift

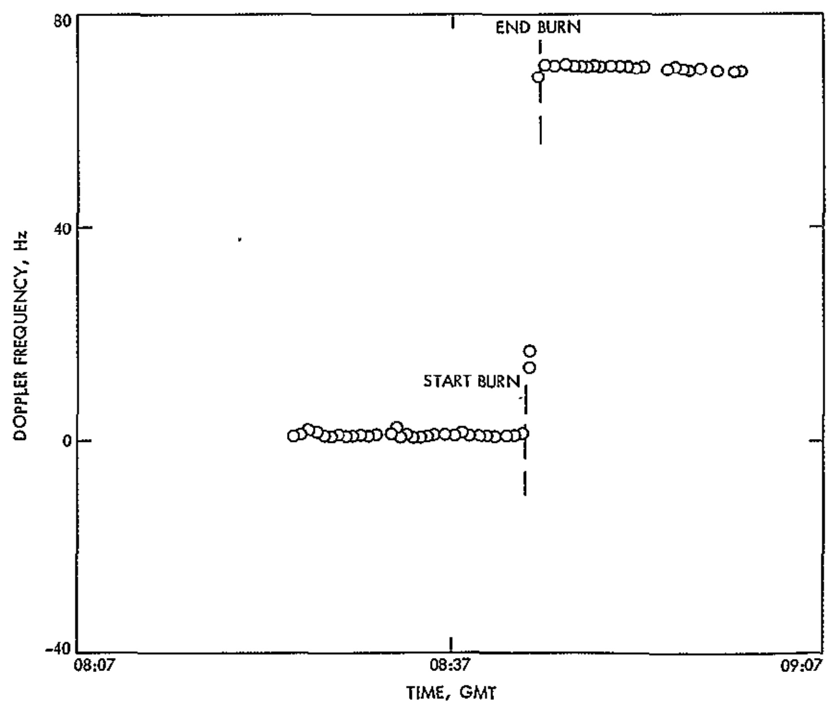

Fig. 91. Mission V first orbit change doppler shift

determination. During photo readout, data noise increased but did not have any significant effect on data reduction. The difficulties associated with obtaining transmitter frequency reports during previous missions were at a minimum during Mission V.

There were many spacecraft orientation maneuvers during the orbit phase which produced small accelerations in spacecraft velocity. As a result, sharp breaks quite often appeared in the data. These small forces were not accounted for in the orbit determination process; as a result, precision orbit determination using long spans of these data may be poor.

There was excellent cooperation with the Project and all technical and operational procedures were satisfactory.

F. DSN Monitor System Performance

1. Performance summary. DSN monitor support began at $L - 2$ hours and continued around the clock until the end of the photographic phase of the mission on August 19, 1967. Activities included monitoring and validation of both tracking and telemetry data received via teletype and high-speed data lines. To a limited degree, teletype command data were monitored. Backup tracking data were recorded on IBM cards during mission-critical periods (launch, midcourse, lunar injection) and at the Project's request.

The following general functions for monitoring tracking and telemetry data were performed by the DSN Monitor Team:

(1) Monitoring of all incoming tracking and telemetry data.

(2) Ascertaining that tracking and telemetry data were received in the proper format.

(3) Logging information pertinent to the received data.

2. Tracking data validation. Tracking data validation consisted of continuous monitoring of incoming teletype data for (1) correct preambles (data identification codes) inserted at the appropriate times, and (2) proper AFETR and DSIF formats. Information such as total data points received, data condition codes, anomalies, etc, were logged. Reperforators and IBM 047 tape-to-card punches were used to provide a backup tracking data source during the mission-critical phases. Cards were punched from L to $L + 6$ h, from midcourse -2 h to midcourse $+1$ h, and from injection -2 h to injection $+2$ h. Reperforator tapes were produced throughout the period from launch to injection $+2$ h. Additional cards were punched during the support period as requested by the Project.

Primary data losses were due to communication failures which injected extra characters into the data stream or caused garbling of the tracking data. During normal operation, bad data condition codes caused the majority of unusual samples. Tracking data results are summarized in Table 53.

Table 53. Tracking data monitoring summary

Station	Total samples	Total with bad data condition codes	Total garbled	Total usable samples	Usable data, %[a]
AFETR	459	33	6	425	92.59
DSS 51	310	28	22	260	83.88
DSS 41	13,213	303	255	12,097	94.99
DSS 62	12,238	1,059	196	10,989	88.10
DSS 12	13,209	1,160	146	11,536	91.42
Total	39,429	2,583	625	35,301	90.89

[a]Percentages computed with data compressed to one-min sample rates.

3. Telemetry data validation. Telemetry data received via teletype and HSDL were monitored for the following:

(1) Insertion of correct preambles at appropriate times.

(2) Proper headers.

(3) Proper number of blocks (lines) per TCP edit mode.

(4) Proper number of characters per block.

(5) Proper frame sync.

(6) Proper Δt between frames.

(7) Correct GMT.

(8) Parity errors.

All anomalies observed were logged and categorized as either a DSN responsibility or a Flight Project responsibility (e.g., attributable to the spacecraft). The total number of frames and the total number of blocks containing anomalies were tabulated. The results of these tabulations, together with their corresponding percentages, are summarized in Tables 54 and 55. Telemetry data received via high-speed data line were not available to the Monitor Team on a continuous basis since the bulk

Table 54. Teletype telemetry data monitoring summary

Description	Deep Space Station				Totals
	71	41	62	12	
Total passes	1	17	17	16	51
Total frames monitored	1007	20788	18817	19532	60144
Total number of good frames received at SFOF	922	18817	17814	19145	56768
Good frames received, %	98.51	90.51	94.66	98.01	95.42
Total blocks monitored	6042	117425	103034	106614	327115
Total number of good blocks received at SFOF	5287	112638	100266	98716	316907
Good blocks received, %	99.09	95.92	97.31	92.59	96.22
Total number of bad frames[a]	15.0	1971	1003	387	3376
Bad frames,[a] %	1.49	9.49	5.44	1.99	4.60
Total number of bad frames[a]	85.	4787	2768	7898	15538
Bad blocks,[a] %	1.40	4.08	2.69	7.41	3.89

[a]A bad frame or block was defined as one which violated one or more of the criteria set forth in paragraph F. 3. of Part VI, Section IV above.

Table 55. HSDL (prime) telemetry data monitoring summary

Description	Deep Space Station				Totals
	71	41	62	12	
Total passes	1	17	17	16	51
Total frames monitored	1058	21374	18842	20279	61553
Total number of good frames received at SFOF	882	18187	16363	16747	52179
Good frames received, %	83.36	85.08	86.84	82.85	84.77
Total number of bad frames[a]	170	3187	2476	1532	7365
Bad frames,[a] %	6.64	14.92	13.16	7.42	5.23

[a]A bad frame or block was defined as one which violated one or more of the criteria set forth in paragraph F. 3. of Part VI, Section IV above.

printer used for display was utilized on a share basis with the Project. High-speed data line outages and data anomalies were cross-checked with the data received via teletype.

4. Command data monitoring. Teletype command data in limited amounts were monitored for the first time during Mission V. Equipment limitations within the DSN Monitor Area restricted monitor activities to only those data involving the prime, or two-way, DSIF station. These data were monitored for the following:

(1) Correct NASCOM headers.

(2) Correct sequencing within the command series.

(3) Proper indication of DSS verification.

(4) Alarm conditions (e.g., line stoppages, illegal characters, etc.).

5. Conclusion. Overall DSN performance with respect to real-time data recovery was not comparable to the support provided for previous *Lunar Orbiter* missions. Real-time recovery of TTY telemetry data and tracking data exceeded 95% and 90%, respectively.

Appendix A

Configuration and Data Flow Diagrams

Table 54. Teletype telemetry data monitoring summary

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5. Conclusion. Overall DSN performance with respect to real-time data recovery was not comparable to the support provided for previous *Lunar Orbiter* missions. Real-time recovery of TTY telemetry data and tracking data exceeded 95% and 90%, respectively.

determination. During photo readout, data noise increased but did not have any significant effect on data reduction. The difficulties associated with obtaining transmitter frequency reports during previous missions were at a minimum during Mission V.

There were many spacecraft orientation maneuvers during the orbit phase which produced small accelerations in spacecraft velocity. As a result, sharp breaks quite often appeared in the data. These small forces were not accounted for in the orbit determination process; as a result, precision orbit determination using long spans of these data may be poor.

There was excellent cooperation with the Project and all technical and operational procedures were satisfactory.

F. DSN Monitor System Performance

1. Performance summary. DSN monitor support began at $L - 2$ hours and continued around the clock until the end of the photographic phase of the mission on August 19, 1967. Activities included monitoring and validation of both tracking and telemetry data received via teletype and high-speed data lines. To a limited degree, teletype command data were monitored. Backup tracking data were recorded on IBM cards during mission-critical periods (launch, midcourse, lunar injection) and at the Project's request.

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(5) Proper frame sync.

(6) Proper Δt between frames.

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Appendix A

Configuration and Data Flow Diagrams

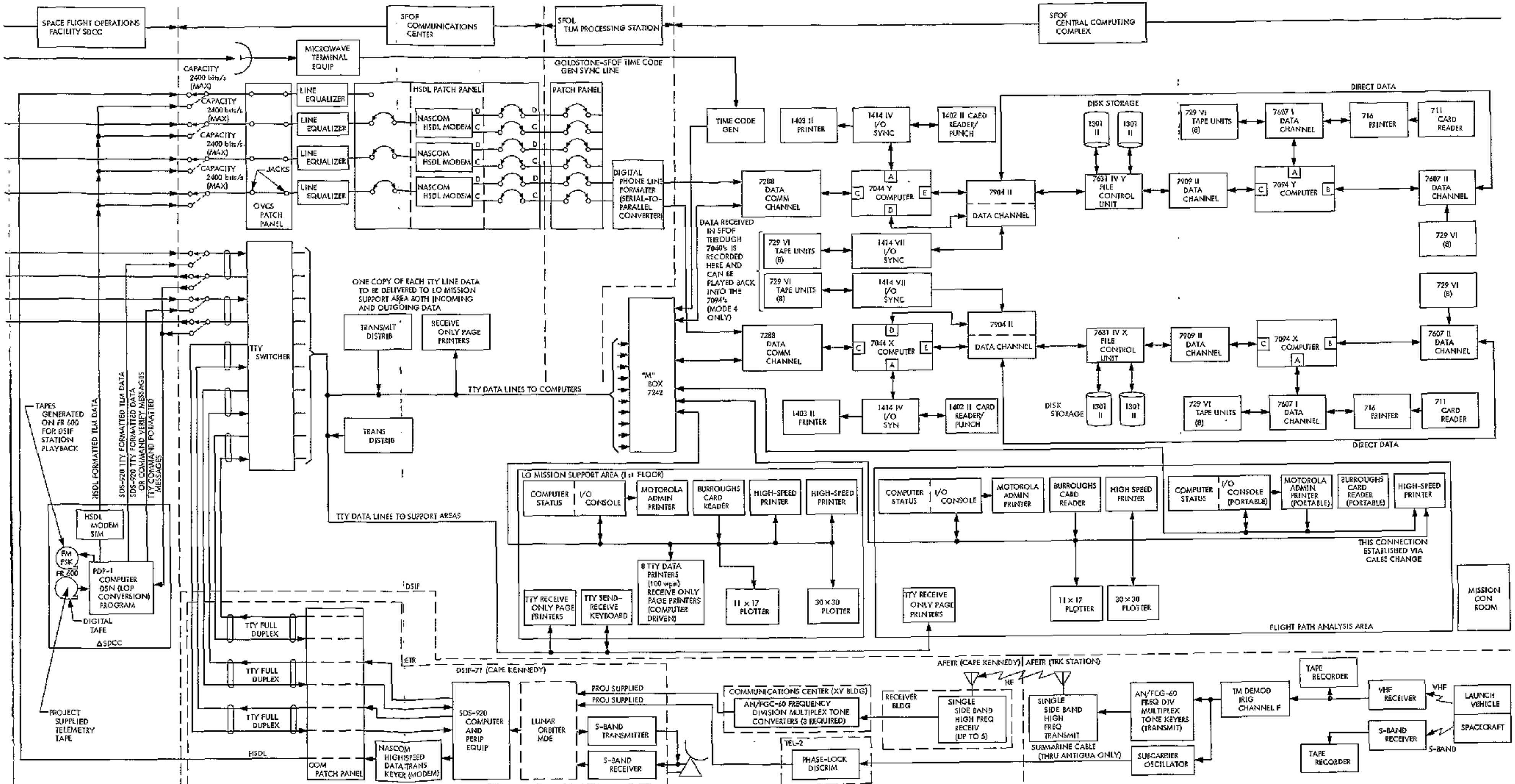

Fig. A-1. *Lunar Orbiter overall telemetry and command data flow diagram*

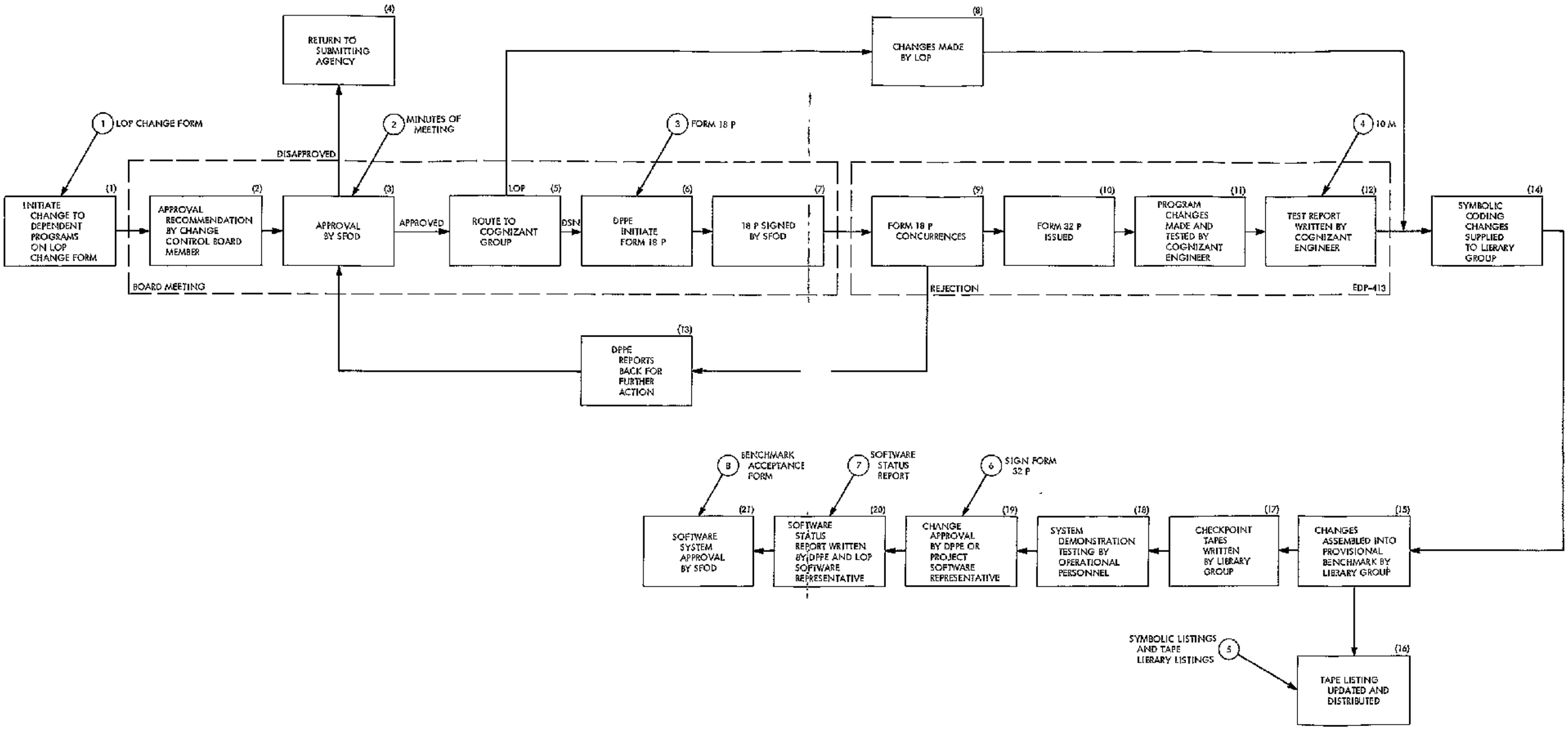

Fig. A-2. Software change control system

A

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Appendix B

Performance Data

Table B-1. DSN design/performance parameter summary

Parameter	Value
A. DSIF	
1. Antenna gain—Transmit	51 dB
Antenna gain—Receive	53.5 dB
2. Antenna pointing error (>20 dB S/N)	0.05 deg
3. Antenna temperature	55°K
4. Maximum transmit power	10 kW
5. Ranging accuracy	15 m
6. Doppler accuracy	0.1 mm/s
7. Telemetry/Command Processor—Add rate	8 μs
Telemetry/Command Processor—Memory	8 k words
8. Signal level measurement accuracy	2 dB
9. DSIF interstation time correlation accuracy	<20 μs
B. GCF	
1. Data rate, HSDL (from DSIF stations)	2400 bps
2. Error rate, HSDL	$<10^{-6}$
3. Data rate, TTY	100 wpm
4. Error rate, TTY (from DSIF stations)	$<10^{-4}$
5. Video bandwidth (GTS-SFOF only)	6 Mhz
6. Video S/N, microwave link	>40 dB
7. Voice S/N (from DSIF stations)	>20 dB
C. SFOF	
1. Central Processor (7044/94) memory	Core: 64 K (44) and 32 K (94) words Disk: 112 × 10^6 characters
2. Central Processor add rate	2 μs
3. Central Processor MTBF (Restart)	8 h
4. Operating system links, DSN software	13
5. Analysis links, *Lunar Orbiter* Project software	28
6. Remote I/O devices for *Lunar Orbiter* Project analysis areas	5
D. NAVIGATION, TYPICAL PERFORMANCE	
1. *Lunar Orbit* insertion accuracy, 3σ, B plane:	B • T 10 km B • R 10 km T 4 s
2. *Lunar Orbiter* position accuracy predictions, 3σ (previous orbit tracking observables)	Longitude, 1 km Latitude, 1 km Altitude, 100 m

Table B-2. Monitor summary of good data received at SFOF

DSS	Metric data, %				Telemetry data, % HSDL			Telemetry data, % TTY			
	II[a]	III	IV	V	III	IV	V	II	III	IV	V
41	Not Monitored	83.57	94.61	94.99	Not Monitored	Not Monitored	85.08	95.90	95.20	93.79	90.41
61/62		92.23	93.34	88.10			86.84	96.13	96.93	95.32	94.66
12		96.69	93.57	91.42			82.85	98.78	100.00	98.23	97.47

[a]Monitor system was not operational during Mission I

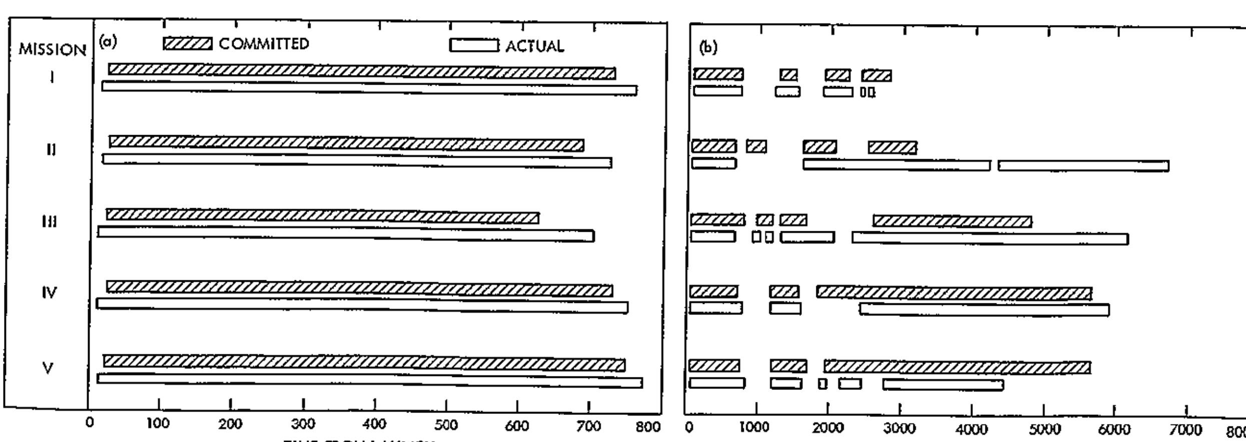

Fig. B-1. Composite AFETR and MSFN metric coverage

Table B-3. Discrepancy reports generated against the DSIF during each *Lunar Orbiter* mission

Period for which data was taken	Antenna	Receiver	Trans-mitter	Ranging system	Tracking data handling	Telem-etry and command pro-cessor	Recorder	Fre-quency and Timing Sub-system	Micro wave	Acquisi-tion aid	Station instru-menta-tion	Other	Total
Mission I Aug. 10, 1966 Aug. 29, 1966		3	3		4	2	1	1		1	1	4	20
Mission II Nov. 6, 1966 Oct. 10, 1967	10	18	9	5	13	8	3	4	1	1	4	14	90
Mission III Feb. 4, 1967 Oct. 9, 1967	5	9	3	3	14	4	2	4	2		6	16	68
Mission IV May 4, 1967 Aug. 16, 1967	3	7	8	1	10	1	2	1	4		4	7	48
Mission V Aug. 1, 1967 Nov. 20, 1967	6	11	11	6	9	4	3	3	1		3	4	61
Totals	24	48	34	15	50	19	11	13	8	2	18	48	287

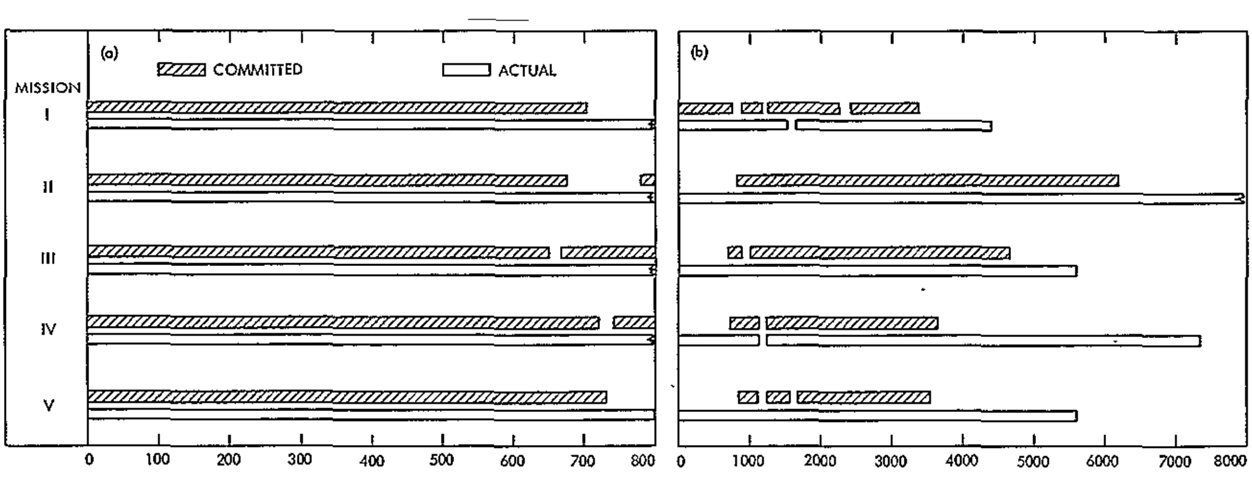

Fig. B-2. Composite AFETR and MSFN VHF coverage

Table B-4. Discrepancy report summary for the SFOF data processing system and intra communications system during Missions III, IV, and V

Type of discrepancy		Mission III		Mission IV		Mission V	
		DPS[a]	ICS[a]	DPS	ICS	DPS	ICS
Procedural	Reports	12	—	4	1	4	—
	Mission total, %	8.6	—	2.9	0.7	2.8	—
Hardware	Reports	51	53	71	32	91	15
	Mission total, %	36.4	37.8	50.7	22.9	64.5	10.7
Software	Reports	4[b]	—	7[c]	—	12	—
	Mission total, %	2.9	—	5.0	—	8.5	—
No trouble found (Undetermined)	Reports	14	6	15	10	15	4
	Mission total, %	10.0	4.3	10.7	7.1	10.7	2.8
System totals, reports		81[b]	59	97[c]	43	122	19
Mission totals, reports		140		140		141	
Report interval		Feb. 4 to Mar. 8, 1967 (32 days)		Apr. 23 to June 6, 1967 (45 days)		July 24 to Aug. 8, 1967 (34 days)	

[a]See Glossary.
[b]13 Communications errors not included.
[c]44 Communications errors not included.

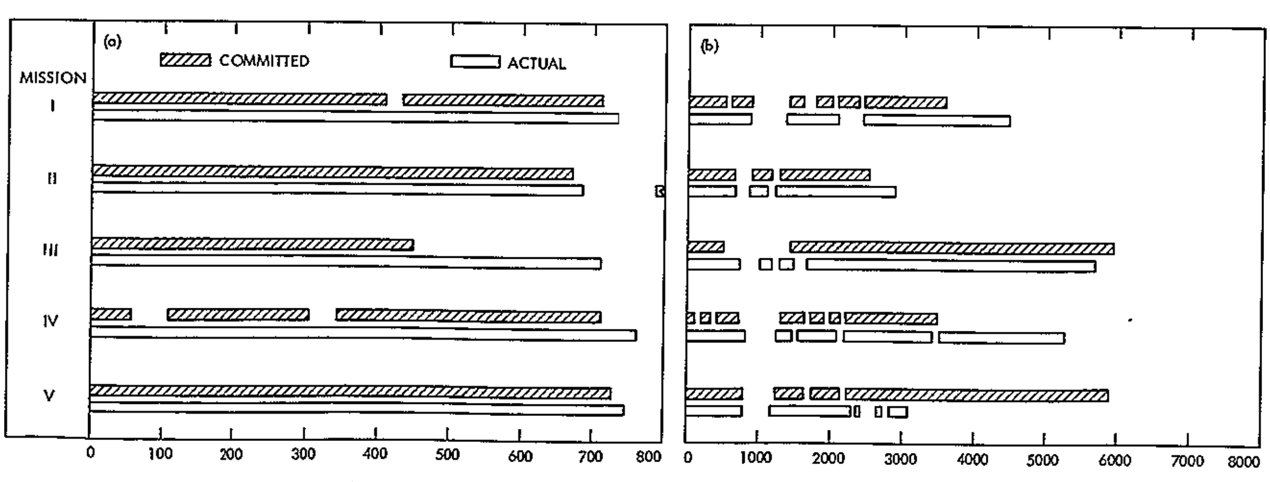

Fig. B-3. Composite AFETR and MSFN S-band coverage

Table B-5. DSN discrepancy report totals per project through Sept. 1967

Project	Reports, No. of	Total, %
Lunar Orbiter	2,631	20
Mariner	3,141	23.9
Surveyor	2,546	19.3
Pioneer	950	7.2
Non-project specific	3,885	29.6
Grand total	13,153	100.0

Table B-6. DSN discrepancy report totals for *Lunar Orbiter*

Mission	Reports, No. of	Total, %
I	940	35.7
II	311	11.8
III	530	20.2
IV	486	18.5
V	364	13.8
Grand total	2,631	100.0

Appendix C

DSN Resources:
Personnel, Man-Hours, and Facility Loading Data

Table C-1. DSN SFOF utilization summary

Mission: Lunar Orbiter	*I*		*II*		*III*		*IV*		V	
Begin mission tests	Apr. 3, 1966		Oct. 10, 1966		Jan. 7, 1967		Apr. 1, 1967		July 24, 1967	
Launch date time, GMT	Aug. 10, 1966/19:26		Nov. 6, 1966/23:21		Feb. 5, 1967/01:17		Mar. 4, 1967/22:25		Aug. 1, 1967/22:33	
End photo phase	*L* + 35 days		*L* + 31 days		*L* + 34 days		*L* + 29 days		*L* + 28 days	
Reason	Nominal mission		TWTA failed		Nominal mission		Nominal mission		Nominal mission	
End extended mission	Oct. 29, 1966		Oct. 11, 1967		Oct. 9, 1967		July 21, 1967		Jan. 31, 1968	
Reason	Deliberate impact		Deliberate impact		Deliberate impact		Lost		Deliberate impact	
OCC scheduling effort[a]	Test	Mission	Test	Mission	Test	Mission	Test	Mission	Test	Mission
Lunar Orbiter operations performed	—[b]	—	—	—	198	232	112	168	51	125
Total tests in DSN	—	—	—	—	1186	2124	1059	1390	318	1233
Lunar Orbiter operations, %	—	—	—	—	16.7	10.9	10.5	12.1	16	10.1
Lunar Orbiter changes to schedule	—	—	—	—	99	217	151	128	24	67
Total changes in DSN	—	—	—	—	406	801	629	765	125	465
Lunar Orbiter changes, %	—	—	—	—	24.4	27.7	24.0	16.7	19.2	14.4
DPS[c] utilization, wk	18	6	4	5	4	5	4	6	1	5
7044 h/% available	1472/24.4	1136.1/56.4	278.3/20.8	890.9/53.5	434.0/21.5	1136.7/45	479.7/23.8	1096/27.2	271/40.3	1082.8/32.2
7094 h/% available	1934.1/32	1240.7/61.8	309.9/23	928.2/55.2	459.7/22.8	1184.0/47	426.2/21.2	1200.7/29.8	270/40.2	1096.1/32.6
TPS–DPLF time used, h	667.6	945.3	—[b]	—	—	—	—	—	—	—
7044 or 7094 time available, h/wk	336	336	336	336	504	504	504	672	672	672
SDCC[c] utilization weeks (since June 11, 1966)	8	6	4	5	4	5	4	5	1	5
PDP-1 Computer	136	—	186	78	196	83	67	23	34	0
ASI-6050 Computer	—	—	—	—	—	—	165	22	205	0
TTY	361	59	145	78	196	0	141	62	0	0
Recording	0	0	30	0	24	0	0	0	0	0
DSIF time, h	Data not available	1004	185	819	313	941	210	783	264	752
Man-hours per wk, h	506	2661	750	2832	558	3024	1000	3330	220	3353
Overtime per wk, h	68	405	34	151	16	141	90	243	186	286

[a]Period covers start of mission tests to end of photo phase approximately 9 wk for Missions I through IV and 6 weeks for Mission V.
[b]Data not available.
[c]See Glossary.

Table C-2. Total DSIF coverage summary for photographic and extended-mission phases

Item	Time expended per mission, h				
	I	II	III	IV	V
Two-way tracking	1107.17	1294.95	1206.84	845.34	595.90
Three-way tracking	183.07	244.65	312.00	222.31	156.25
Total tracking	1290.24	1539.60	1518.96	1067.66	752.17
Ranging	167.16	368.10	215.46	158.82	48.48
Time correlations	3.13	1.48	1.68	5.18	2.17
Operational readiness tests	38	38	38	38	38
Pre/post calibrations	588	476	546	455	441
Total time, h	3376.77	3962.78	3828.94	3792.31	2034.07

Table C-3. SFOF manpower estimates for *Lunar Orbiter I–V*

Mission	Premission phase (ORTs)			Photographic mission phase		
	Straight time, h	Overtime, h	Period, wk	Straight time, h	Overtime, h	Period, wk
I	9100	1220	18	15,968	2429	6
II	3000	135	4	14,168	756	5
III	2232[a]	63.5[a]	4	15,112	707	5
IV	4000	362	4	16,648	1215.8	5
V	222	186	1	16,768	286	5

[a]Time for premission support from DSS in Table C-1 for Mission III is 31 h. This appears low for a 4-wk period and is assumed to represent only the week before launch. Percentage of use was calculated on a 1-wk basis and projected. Because of overlap between training and extended mission support for previous missions, premission times for II–V are approximations.

Table C-4. SFOF communications group support man-hours

Mission	Premission phase (ORTs)		Launch through end of mission	
	Straight time, h	Overtime, h	Straight time, h	Overtime, h
I	1,828.1	799.5	2,876.4	575.5
II	1,401.7	47.0	2,638.1	118.0
III	742.5	38.7	2,777.9	228.5
IV	478.0	101.5	2,448.3	240.0
V	791.5	77.5	1,717.5	171.3
Totals	5,241.8	1,064.2	12,458.2	1,333.3

Table C-5. DSIF man-hours

Mission	I	II	III	IV	V
DSS, h	14,751	11,997	13,734	11,484	11,079
Net control, h	940	1,060	1,060	1,060	1,080
Totals, h	15,691	13,057	14,794	12,544	12,159

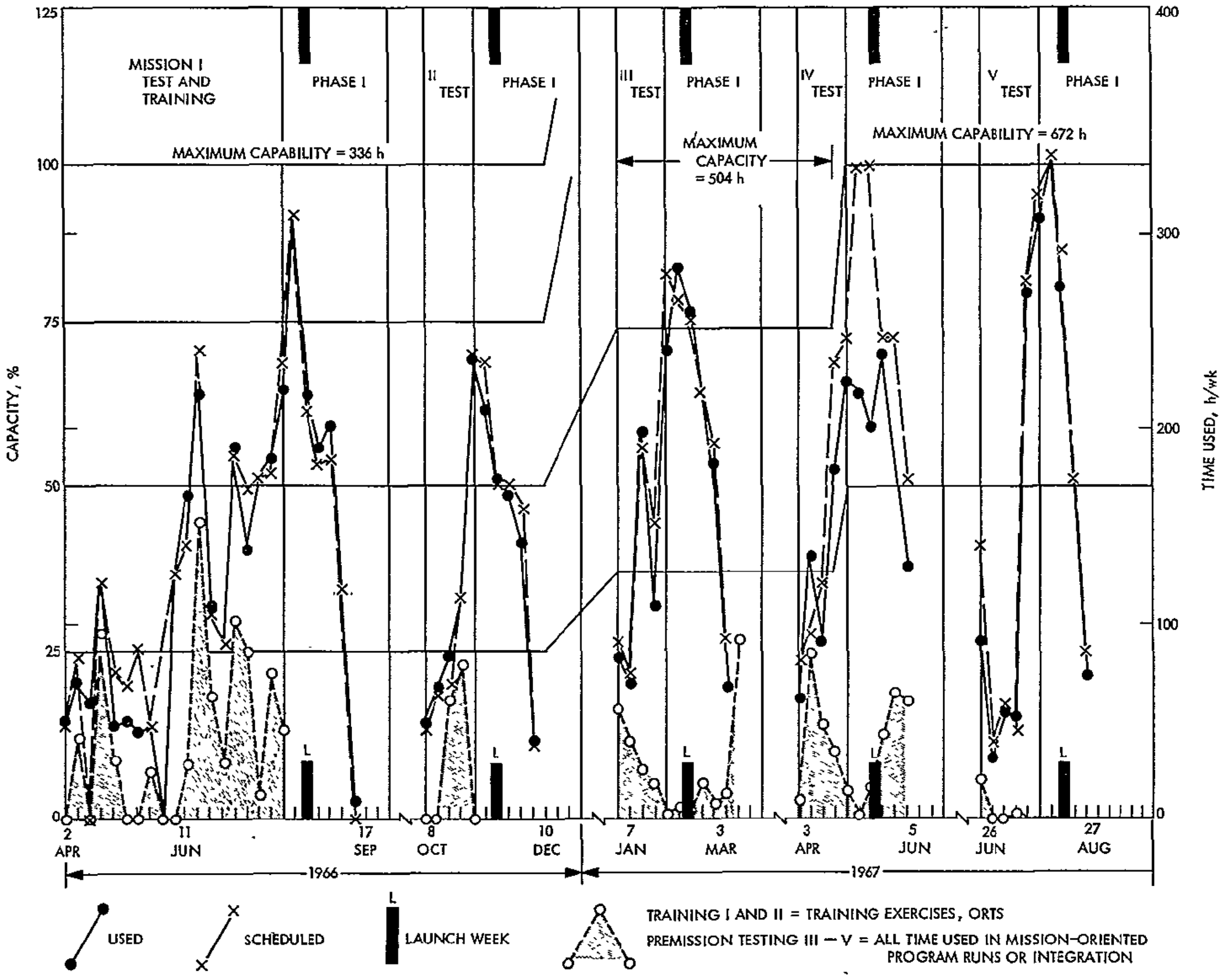

Fig. C-1. IBM 7094 Computer utilization for *Lunar Orbiter I–V*

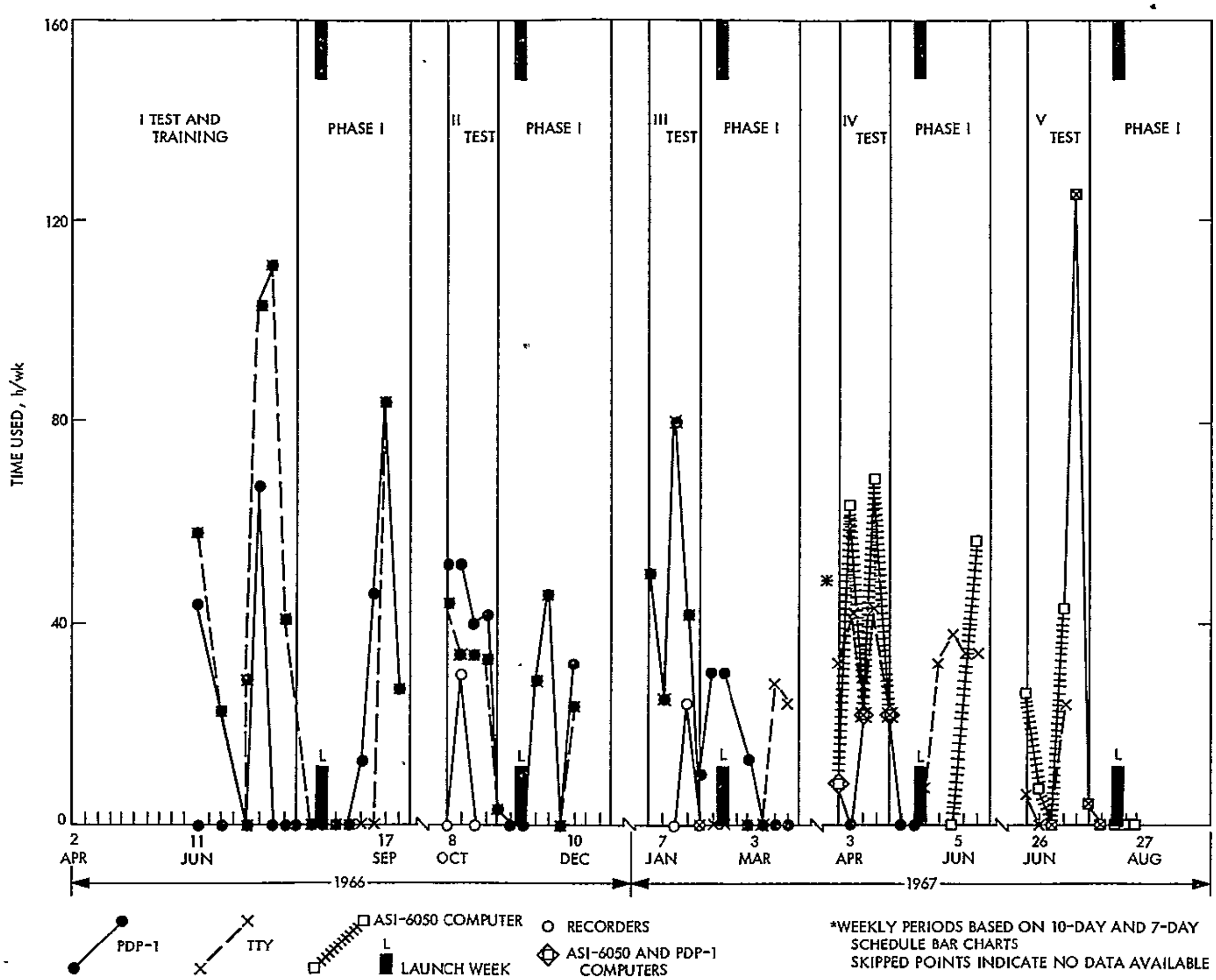

Fig. C-2. SDCC utilization for *Lunar Orbiter I–V*

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Glossary (contd)

SFOD	Space Flight Operations Director
SFOF	Space Flight Operations Facility
SIRD	Support Instrumentation Requirements Document
SLOE	Senior *Lunar Orbiter* Engineer
SMC	Station Control and Monitor Console
SNOMAN	Supervisor of Network Operations
SOPM	standard orbital parameter message
SPAC	Spacecraft Performance Analysis and Command
TCP	telemetry and command processor
TDA	Tracking and Data Acquisition
TDH	Tracking Data Handling Subsystem (DSIF)
TDM	Tracking Data Monitor
TDP	Tracking Data Processor
TDS	Tracking and Data System
TDQD	tracking data quality determination
Tel-2, -4	Telemetry Bldgs at AFETR
TIM	Tracking Instruction Manual
TLM	telemetry
TO	transfer orbit
TPS	Telemetry Processing Station (SFOF)
TRK	tracking
TTY	teletype
TWTA	traveling wave tube amplifier
VCO	voltage-controlled oscillator
VECO	vernier engine cutoff
WTR	Western Test Range
X_A	ground transmitter VCO frequency setting

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Glossary

AFETR	Air Force Eastern Test Range
AGC	automatic gain control
AGNQ	*Apollo* GOSS/Navigation Qualification
AOS	acquisition of signal
APS	antenna pointing system
BCD	binary-coded decimal
BECO	booster engine cutoff
BIH	built-in hold
CCTV	closed circuit television
COMM	communications
COMSAT	communications satellite
CP	communications processor
DACON	call sign for data control function
DIS	Digital Instrumentation Subsystem
DPLF	digital phone line formatter
DPPE	Data Processing Project Engineer
DPS	Data Processing System
DRS	Discrepancy Reporting System
DSIF	Deep Space Instrumentation Facility
DSN	Deep Space Network
DSS	Deep Space Station
FPAC	Flight Path Analysis and Command
FSK	frequency shift keying
FSM	frequency shift modulation
FTS	Frequency and Timing Subsystem
GCF	Ground Communications Facility
GET	ground elapsed time
GMT	Greenwich Meridian Time
GOSS	Ground Operational Support System
GRE	ground reconstruction electronics
GSFC	Goddard Space Flight Center
HF	high frequency
HSD	high-speed data
HSDL	high-speed data line
ICS	Intra-Communication System
IMP	Interim Monitor Program
I/O	input/output
IRV	interrange vector
KSC	Kennedy Space Center
L&PO	Lunar and Planetary Office
LOP	*Lunar Orbiter* Project
LOS	loss of signal
LRC	Langley Research Center
MCR	Mission Control Room
MDE	mission-dependent equipment
MOC	MSFN Mission Operations Center
MSFN	Manned Space Flight Network
MTBF	mean-time between failures
NASCOM	NASA Communications Network
NOR	not operationally ready
NSP	NASA Support Plan
OCC	Operations Control Chief
OD	orbit determination
ODG	orbit data generator
ODP	Orbit Determination Program
OR	operation requirement
ORT	Operational Readiness Test
OSSA	Office of Space Science and Applications
OTDA	Office of Tracking and Data Acquisition
OVCS	Operational Voice Communications Subsystem
OVT	Operational Verification Tests
PSP	Project Support Plan
PE	Project Engineer
PO	parking orbit
POWL	a computer program (for powered flight)
PRD	Program Requirements Document
PRDL	a computer program (a prediction program)
RIS	Range Instrumentation Ship
RNG	Ranging System
RTCS	Real-Time Computer System
SAA	S-band acquisition aid antenna
SDA	Systems Data Analyst
SDCC	Simulation Data Conversion Center
SECO	sustainer engine cutoff