NASA

National Aeronautics and
Space Administration

Washington, D.C.
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APR 13 1989

Reply to Attn of: EL

TO: A/Administrator

FROM: E/Associate Administrator for Space Science and Applications

SUBJECT: Magellan Prelaunch Mission Operations Report

The single Magellan spacecraft will be launched from KSC on board Atlantis (STS-30) on April 28, 1989, at 2:24 p.m. EDT. The nominal launch period extends from April 28 to May 24; the overall launch period can be extended to as late as May 28 if certain compromises are made in the deployment constraints and Venus orbital insertion changes accepted. The daily launch window increases from 23 minutes the first day to 121 minutes on the 16th day and remains at 121 minutes through the remainder of the period.

Following Shuttle insertion into a 296 km parking orbit inclined at 28.85^{o}, the combined Magellan spacecraft/2-Stage IUS will be deployed from Atlantis on Rev 5 (6:17 hrs MET). Approximately one hour later, the IUS will ignite and inject the Magellan spacecraft onto an Earth-Venus transfer trajectory. Separation of the Magellan spacecraft from the depleted IUS will occur at 7:42 hrs MET.

The Magellan spacecraft is powered by single degree-of-freedom sun-tracking solar panels. The spacecraft is 3-axis stabilized by reaction wheels using gyros and a star sensor for attitude reference. The spacecraft carries a large solid rocket motor for Venus Orbit Insertion (VOI). A small hydrazine system with thrusters ranging from 0.9N to 445N provides Delta-V for trajectory correction maneuvers and certain attitude control functions. Earth communication with the Deep Space Network (DSN) will be conducted in both S- and X-band channels using low and medium gain antennas and a 3.7 m high gain antenna rigidly attached to the spacecraft. The high-gain antenna also functions as the Synthetic Aperture Radar antenna during mapping operations at Venus.

The interplanetary cruise phase will last 15 months with arrival at Venus at 17:00 GMT on August 10, 1990, independent of the precise launch day or time. During the cruise phase, small trajectory correction maneuvers are planned to adjust the Venus approach geometry with the final maneuver performed 17 days prior to VOI. After VOI (which occurs behind the planet as seen from Earth) the spacecraft will be tracked by the DSN and orbit trim maneuvers performed if necessary.

The Venus mapping orbit will have a periapsis altitude of 250 km (located at 10 deg N), an apoapsis altitude of 8029 km, a period of 3.15 hrs, and an inclination of 86.0 deg. After an 18-day In-Orbit Checkout period, the spacecraft will begin a systematic mapping of the planet lasting for 243 days, the time required for one planetary rotation beneath the Magellan mapping orbit.

The data acquired each orbit will be transmitted and received by the Deep Space Network. Limited assessment of the radar data will be performed as received to ensure that the data quality are within specifications. More complete and comprehensive processing of the radar sensor data will be performed by special data processing facilities at JPL for subsequent scientific analysis.

The nominal Magellan mission will end April 28, 1991.

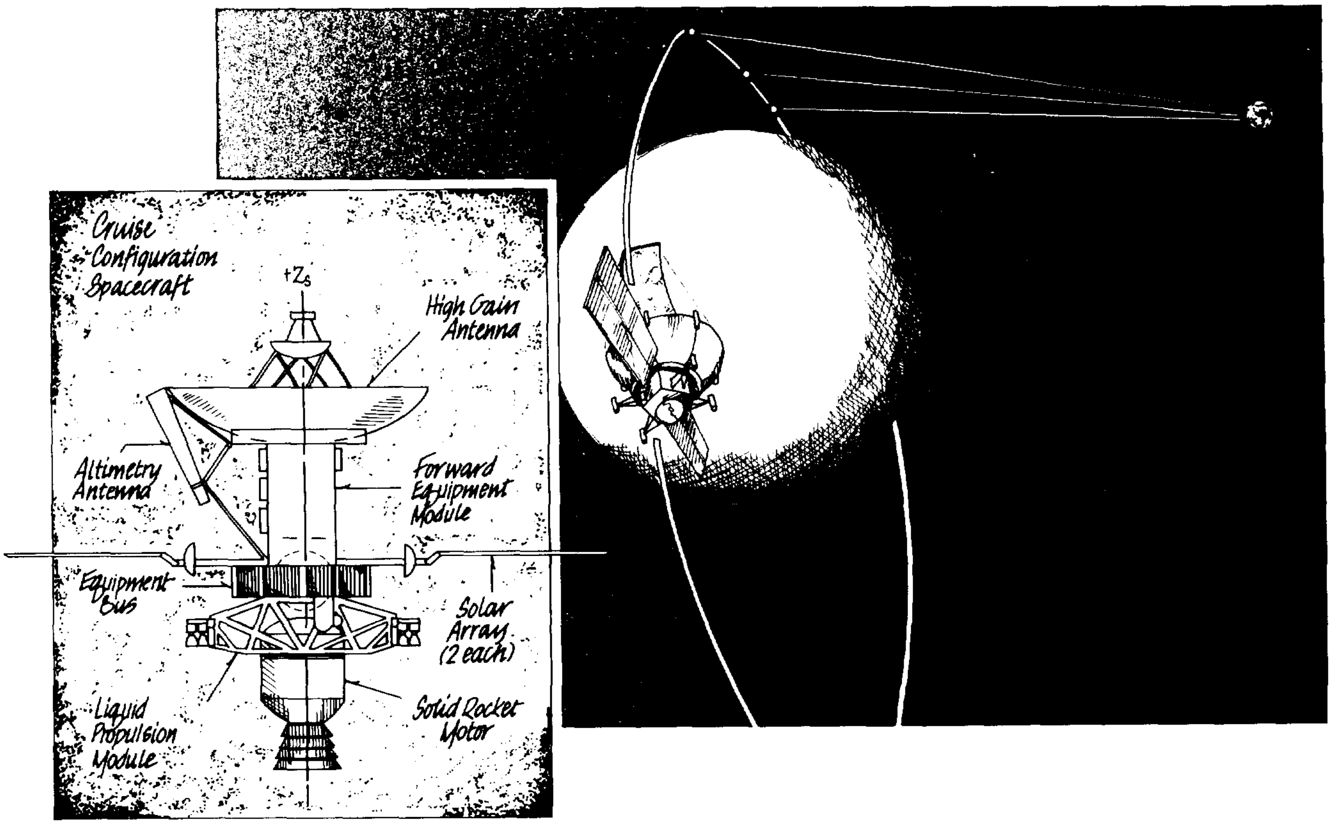
L. A. Fisk

National Aeronautics and
Space Administration

Mission Operation Report

OFFICE OF SPACE SCIENCE AND APPLICATIONS

Report No. E-844-89-30-01



Magellan

MISSION OPERATION REPORT

FOREWORD

MISSION OPERATION REPORTS are published expressly for the use of NASA senior management. The purpose of these reports is to provide NASA senior management with timely, complete, and definitive information on flight mission plans, and to establish official mission objectives which provide the basis for assessment of mission accomplishment.

Reports are prepared and issued for each flight project just prior to launch. Following launch, updating reports for each mission are issued to keep management currently informed of definitive mission results as provided in NASA Management Instruction HQMI 8610.1B.

These reports are sometimes highly technical and are for personnel having program/project management responsibilities. The Public Affairs Division publishes a comprehensive series of reports on NASA flight missions which are available for dissemination to the news media.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

MISSION SUMMARY

The Magellan spacecraft will be launched from Kennedy Space Center (KSC) within a 31-day overall launch period extending from April 28 to May 28, 1989. The launch will use the Shuttle Orbiter Atlantis to lift an Inertial Upper Stage (IUS) and the Magellan spacecraft into low Earth orbit. After the Shuttle achieves its parking orbit, the IUS and attached Magellan spacecraft are deployed from the payload bay. After a short coast time, the two-stage IUS is fired to inject the Magellan spacecraft into an Earth-Venus transfer trajectory.

The Magellan spacecraft is powered by single degree of freedom, sun-tracking, solar panels charging a set of nickle-cadmium batteries. The spacecraft is three-axis stabilized by reaction wheels using gyros and a star sensor for attitude reference. The spacecraft carries a solid rocket motor for Venus Orbit Insertion (VOI). A hydrazine propulsion system allows trajectory correction and prevents saturation of the reaction wheels. Communication with Earth through the Deep Space Network (DSN) is provided by S- and X-band telemetry channels, through alternatively a low, medium, or 3.7 m high-gain parabolic antenna rigidly attached to the spacecraft. The high-gain antenna also serves as the radar and radiometer antenna during orbit around Venus.

The interplanetary cruise phase lasts approximately 15 months. Magellan will arrive at Venus at 17:00 GMT on August 10, 1990, independent of the precise launch date or time. During the cruise phase, small trajectory correction maneuvers are planned to achieve the precise approach geometry. Based on precision spacecraft tracking, Magellan's STAR-48B solid rocket motor will fire slightly before closest approach to Venus, as the spacecraft enters eclipse from Earth. The desired Venus orbit will be elliptical, with a periapsis latitude of 10° N, periapsis altitude of 250 km, apoapsis altitude of 8029 km, and period of 3.15 hours.

After Venus orbit insertion, precision spacecraft tracking will be used to initiate small orbit adjustment maneuvers to achieve the precise mapping orbit. The radar sensor will be checked out and readied for operation. These orbit adjustment and checkout activities are scheduled to last 18 days, after which science data acquisition begins.

The nominal science data acquisition phase lasts 243 days, the time required for Venus to make a complete rotation under the spacecraft orbit. On each orbit, Magellan collects and records radar data during a portion of the orbit, and then turns and transmits the recorded data to Earth over the remainder of the orbit. Typical activities during a single mapping pass are as follows. As the spacecraft approaches Venus' north pole, it is oriented so that the high-gain antenna points toward the surface of the planet, slightly to the side of the spacecraft's ground track. The radar is turned on as the spacecraft passes over Venus's north pole and illuminates the surface until the spacecraft passes over 67° S. On alternating orbits, the radar swath is biased slightly to the south to reduce redundancy near the north pole and to maximize coverage of the planet. Radar data is recorded for 37.2 minutes on each swath. This recording period is constrained by the volume of radar data which can be transmitted to Earth during the remainder of the orbit. The alternating northern and southern swaths cover the planet from the north pole down to 67° S with sufficient overlap to allow the creation of a complete mosaic map without gaps.

Since the Magellan radar sensor operates at a varying altitude above Venus, the range of look-angles for the SAR is varied from 13° to 44° from nadir during each pass. The radar data are acquired at a data rate of 750 kb/s and stored in a redundant pair of spacecraft tape recorders, together with engineering data. Whenever the radar is operating, it interleaves collection of SAR, altimeter, and radiometer data. Altimeter operation uses a separate fan beam antenna oriented so that it always illuminates nadir while the high-gain antenna is oriented for radar operation. The radar operates in bursts of varying duration, with the pulse repetition frequency and burst duration adjusted to compensate for altitude above the planet's surface.

As Magellan moves away from Venus toward apoapsis, the spacecraft reorients its high-gain antenna toward Earth, and the recorded radar data are transmitted to DSN stations on Earth. This data acquisition and transmission cycle is repeated for each orbit. After 243 days, the planet will have been mapped completely except for the area near the south pole.

The data received by the DSN will also be used for both spacecraft and instrument control. Real-time engineering data will be available whenever Magellan is not eclipsed or engaged in radar operation. During these periods, engineering data is recorded with the radar scientific data and subsequently replayed. Round-the-clock mission operational staff will use this data to monitor spacecraft and instrument status, recalibrate or adjust for anomalies, and to prepare command sequences. Up to three days of satellite commands can be stored on board the spacecraft in advance. Limited assessment of the radar data will be performed immediately to ensure that the quality of the data is within specifications.

For scientific analysis, the radar sensor data are transferred to special data processing facilities at JPL. The SAR, altimeter, and radiometer data are processed to form images, and mosaicked into maps at a range of resolutions and global scales. Throughout the science acquisition phase, Magellan is tracked with high precision by the DSN and this tracking data will be reduced to determine the low order mass distribution within Venus. This gravity data will be especially useful in concert with the radar data to understand the geophysics of Venus, since the SAR, altimeter, and passive radiometer measurements reveal strictly surface features. The complete map products will show the correlation between these surface features and deeper geologic processes reflected in the mass distribution.

The Magellan spacecraft was developed by the Martin Marietta Astronautics Group (MMAG) in Denver, Colorado. The radar sensor was built by the Space and Communications Group of the Hughes Aircraft Company and delivered to MMAG for integration with the spacecraft. Mission operations will be conducted by the Jet Propulsion Laboratory.

MISSION OBJECTIVES

Program Objective

The objective of the Magellan Program is to place a satellite carrying a radar sensor into orbit around Venus in order to obtain scientific data regarding the surface of Venus, to reduce and analyze these data, and to make the results available to the public and the scientific community.

Mission Objectives

- To obtain near global (>70% coverage) radar images of the planet's surface, with resolution equivalent to optical imaging of 1 km per line pair.
- To obtain a near global topographic map with 50-km spatial and 100-m vertical resolution.
- To obtain near global (>76%) gravity field data with 700 km or better resolution and 2-3 milligals accuracy.
- To develop an understanding of the geological evolution of the planet, principally its density distribution and dynamics.

William L. Piotrowski

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Magellan Program Manager

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Director, Solar System Exploration Division

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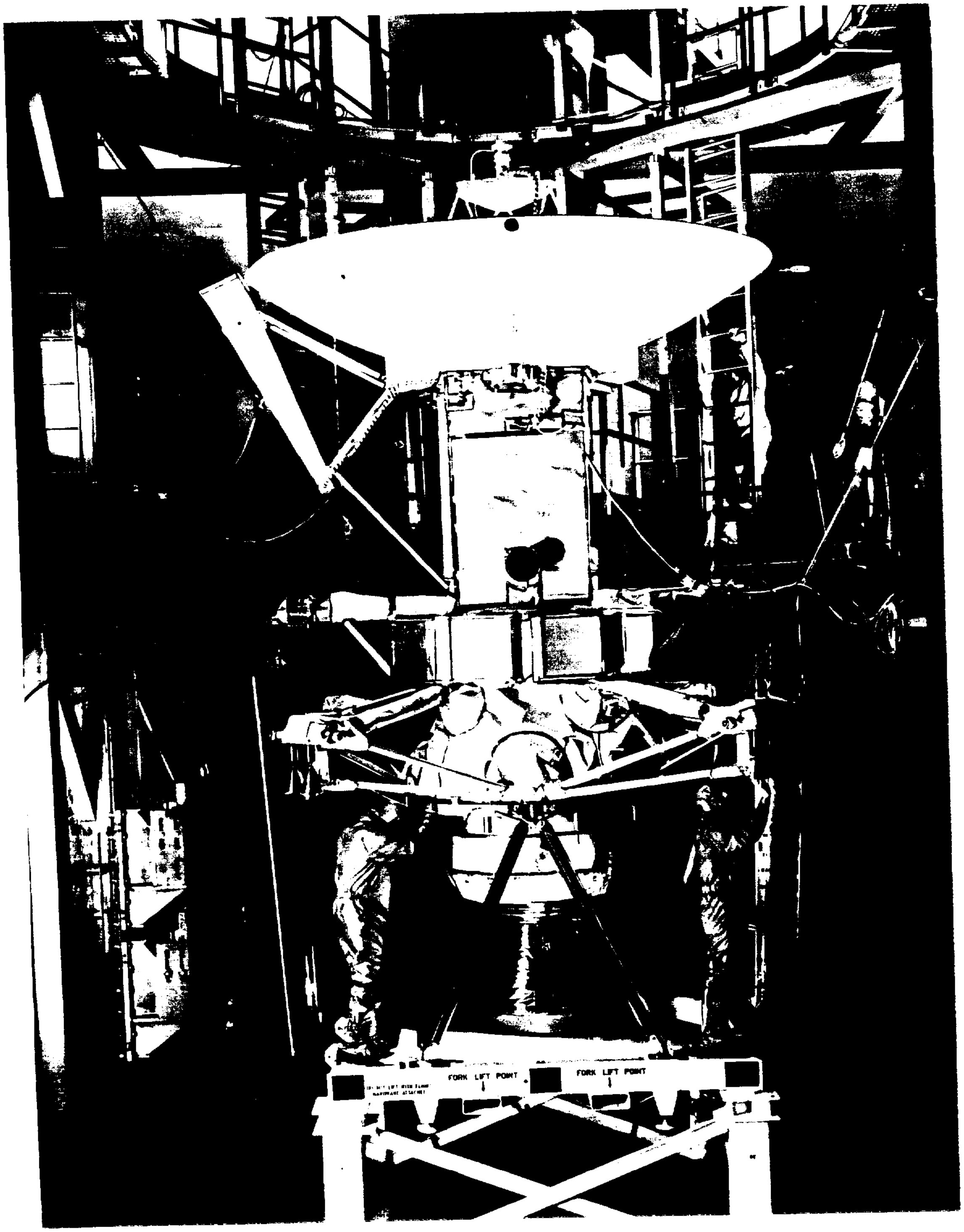
Associate Administrator for the Office
of Space Science and Applications



Magellan Spacecraft (in preparation for acoustic testing at MMAG, Denver)

INTRODUCTION TO MAGELLAN

A mission using a spacecraft radar to obtain a global map of Venus has long been advocated by the planetary science community. Radar is necessary because the cloud cover of Venus prevents any optical remote sensing technique from acquiring data about the surface of the planet. Earth-based radar measurements are able to provide some surface mapping, but the great distance between Earth and Venus and the commensurabilities between the orbits of the two planets restrict the resolution and coverage that can be obtained. Previous spacecraft missions to Venus have studied the Venusian atmosphere and obtained coarse-resolution data on surface topography. The soft landers from the U.S.S.R.'s Venera series and the X-band radar maps from Veneras 15 and 16, which covered the northern hemisphere of Venus above 20° at a resolution of 2-4 km, have made valuable initial contributions to studies of the geology of the most Earth-like of the inner planets. In 1978, the National Research Council (NRC) Space Science Board, in its report entitled Strategy for the Exploration of the Inner Planets: 1977-1987, identified the acquisition of a global map of the topography and morphology of the Venusian surface as the most important goal for Venus exploration.

Early studies of a Venus radar mapping mission generally concentrated on observations that could be made from a spacecraft in a circular orbit about the planet. These studies, conducted in the late 1960s and early 1970s, envisaged missions that could take advantage of the particularly good launch opportunities that were available in the early 1980s. Continued refinement of these studies led to the definition of the Venus Orbiting Imaging Radar (VOIR) as a potential NASA new start.

Planning proceeded for the VOIR mission, and in October 1978 an Announcement of Opportunity (AO) was issued to the scientific community to participate in the mission. Based on proposals submitted in response to that AO a team of investigators was selected in August 1979 including scientists who would use radar, altimeter, and gravity data to study the solid body of Venus, as well as atmospheric investigations. However, the VOIR project was officially canceled in the FY 1983 budget.

Work continued to determine if there was a way to perform a Venus radar mapping mission at lower cost, while preserving the primary science objectives of the VOIR mission. This new mission was to concentrate on solid-body objectives only, and atmospheric experiments were dropped from consideration. Analysis of VOIR showed that the major driver on system characteristics, and thus on the cost of the mission, was the requirement to operate the spacecraft in a low-altitude, circular orbit, in order to simplify the design and data processing for the radar. Studies showed that it would be possible to perform radar mapping from an elliptical orbit, at the cost of variable image resolution and look-angle and some increase in processing complexity. Similar viewing geometry limitations had been accepted for optical imaging systems used on previous planetary missions without serious detriment. Substantial cost savings were also achieved by building the spacecraft from residual flight hardware or standard designs wherever possible. An innovative design using a single parabolic high-gain antenna for both the radar instrument and data communications and a standard existing solid rocket motor for orbit insertion eliminated many of the previous design's costs. The result was a replacement mission for VOIR that satisfied the primary scientific goals for less than half the cost. This new mission, named Venus Radar Mapper (VRM), was endorsed by the NASA Solar System Exploration Committee and by the Committee on Lunar and Planetary Exploration in 1982.

The VRM project was proposed as a new start in the FY 1984 NASA budget and was subsequently approved by the Congress. Overall system responsibility was assigned to the Jet Propulsion Laboratory, together with particular responsibility for the radar data processing systems. Final contracts were let in the fall of 1983 with Martin Marietta Corporation for the spacecraft and Hughes Aircraft Company for the radar sensor.

In November 1985, VRM was formally renamed Magellan (MGN). The *Challenger* accident and subsequent delay in Shuttle missions led to a one year delay in the launch of Magellan and a reevaluation of the launch strategy. Following cancellation of the Centaur upper stage, the Inertial Upper Stage (IUS) was selected as the vehicle to inject Magellan into a transfer orbit to Venus after Shuttle launch into low-earth orbit. This new launch vehicle and launch strategy allowed two major planetary missions to be launched in 1989: Magellan on a Type IV trajectory to Venus in April, and Galileo on a Type II Venus flyby trajectory in October. After launch, Magellan will orbit the sun approximately 1.6 times before arriving at Venus on August 10, 1990. Launch and transfer orbit injection parameters will be adjusted to achieve a constant Venus arrival time independent of the precise launch date.

SCIENCE RATIONALE

Of all the planets, Venus is most nearly Earth's twin in terms of size, mass, and density. Their similarity is striking, although Venus is closer to the sun and receives roughly twice as much solar energy as Earth. However, it is an errant twin that has evolved into a world startlingly different from Earth. As a result, the study of Venus has deep implications for understanding our own planet as well as other members of the Solar System. Earth evolved from the primordial solar nebula into a planet supportive of both primitive and highly evolved life forms. With the growing awareness of long-term, global change in Earth's environment, we need to know much more about why Venus is so different from Earth: why its rotation is slow and in an opposite direction; why it has such a strikingly different atmosphere (100 times as dense as Earth's); what makes its surface hot enough to melt lead; why its magnetic field is so weak; and why Venus lacks significant amounts of oxygen and water. Did Venus ever have oceans? If so, where did they go, and are their traces still detectable?

When examining the science rationale for the Magellan mission, it is important to understand the current status of our understanding of Venus. The Magellan science objectives have been chosen to attack the major gaps in our understanding. A review of the history of Venus exploration is given in the Appendix.

Most previous spacecraft missions to Venus have been principally concerned with its atmosphere, rather than its geology and solid-body geophysics. Therefore, we have a much better understanding of the atmosphere of Venus than of its surface or interior structure and evolution. The principal obstacle to study of the geology of Venus is the dense cloud cover which prevents optical instruments from viewing the surface either from Earth or space. Radar sensors can produce imagery of the surface despite the cloud cover. Such imagery shows both large scale topographic features and differences in microwave reflectivity tied to roughness on very small scales, such as differences in surface rock types.

Earth-based radars have obtained images of the surface of Venus. However, commensurability between the orbital periods of the Earth and Venus and the slow rotation rate of Venus limits Earth-based radar mapping to equatorial and mid-latitude regions of one hemisphere of the planet.

The Pioneer Venus Orbiter acquired radar altimeter data from which a topographic map of essentially the entire planet at approximately 100-km resolution was constructed. These data allow the largest scale physiographic features of the planet to be discerned, but do not have sufficient resolution to identify smaller scale topographic features from which geologic processes that operated or operate on Venus can be identified. Radar maps from Venera 15 and 16 provide substantially better resolution of 2-4 km over the northern hemisphere above 40° N with complete coverage and 20° N with partial. However, both the resolution and limited coverage leave major scientific questions unanswered.

Gravity field observations from the Pioneer Venus Orbiter indicated a high degree of correlation between gravity and large-scale topography, unlike the case on Earth. However, these observations were restricted to the equatorial and mid-latitude regions of the planet. Venus notably lacks a magnetic field similar to Earth's, which is produced by convection in the planet's core. It is unknown whether such differences extend to the convective processes in the mantle associated with plate tectonics.

As well as remote imaging, the Soviet Venera landers provided direct physical measurements for a few very local sites on the surface of the planet. These observations, although extremely important, cannot be realistically extrapolated to a global perspective. Although there was some scientific rationale for selection of the Venera landing sites, their choice was severely constrained by celestial mechanics.

Planets so far explored show a wide range of apparent surface ages, as estimated mainly through studies of the meteor impacts that have affected their surfaces. The surface of Earth's moon has been minimally modified by internal geologic processes in the past three billion years; thus most lunar surface rocks are very ancient. The Earth, on the other hand, has a large internal heat supply that causes its surface to be renewed frequently by volcanism, weathering, or earthquakes. Therefore, many of Earth's surface rocks have ages less than tens of millions of years. Knowledge of the age of the Venusian surface would reveal much about the geologic processes occurring on Venus and the history of the Earthlike (inner solar system) planets.

Clues to the geologic history of a planet are reflected in its surface rocks and features. These surface structures show how the planet has evolved under the influence of internal and external factors. Understanding those factors and the planet's response to them is fundamental to planetary geology.

Plate tectonics is the principal geophysical mechanism responsible for the gross structure of the Earth's surface, including the major division into continents and ocean basins, and secondary features such as deep ocean trenches and spectacular mountain ranges. Since Venus is about the same mass as the Earth (and occupies about the same place in the Solar System), one might expect to find plate tectonic activity. Any successful model for plate tectonics should explain why it occurs on Earth and does, or does not, occur on Venus. We know that Venus, like Earth, has two major topographic levels; unlike Earth, these two levels are not separated by significant vertical displacements, as are Earth's continents and ocean basins, which differ in altitude by more than 4,000 meters. We do not understand the major two-level dichotomy of the Venus surface. We do not know whether the highlands simply represent lateral differences in the composition of the crust, volcanic plateaux, or tectonic structures caused by large-scale (plate tectonic) motion of the Venusian crust. Understanding the origin of these features is critical to the geology of Venus, and is a major goal of the Magellan program.

Geological processes are driven principally by the transfer of heat from the interior to the surface of a planet. On Earth, large-scale heat transfer occurs through mantle convection, which is thought to be a major driver in plate tectonics. There are two competing models for large-scale heat transfer within Venus: Venus may have large-scale convection in a manner similar to the Earth, or it may have highly localized convection, through which heat is transferred in localized mantle plumes that form hot spots on the surface. These two models suggest very different planet surface structures, which can be distinguished by the Magellan imagery.

Today, Venus is utterly devoid of water, but this may not have always been true. Hydrogen/deuterium ratios measured by the Pioneer Venus Orbiter are consistent with the hypothesis that Venus had relatively large amounts of water in the past. If Venus did have oceans, when did they form and how long did they last? Are their traces evident, for example in terraces and beaches that might be discernible with high resolution radar mapping? If Venus did not have oceans, this finding would place strong constraints on the distribution of volatiles in the preplanetary nebula, early solar history, and models of the origin of the solar system.

What can Venus tell us about Earth's history? Venus presents a unique opportunity for comparative planetology relevant to Earth. Its similarity to the Earth in size, bulk composition, and the probable presence of a chemically similar lighter crust implies that differences result from planetary processes that are subtle, responding strongly to small changes. It will suggest sensitive tests for models of geologic processes important on Earth, a notable example being a better understanding of the processes involved in global warming.

The Magellan spacecraft and its radar sensor are designed to provide the information needed to answer these major scientific questions about Venus. Past experience, particularly in the mapping of Mars, has shown that sound understanding of a planet's geology requires that most of the planet be imaged at resolutions of 1 km or better. If coverage is less complete, there is a serious danger that the parts of the planet imaged will not be typical, or show the true range of typical geology, and incorrect conclusions may be drawn concerning global geology. If the resolution is poorer than 1 km, sufficient detail will not be seen to allow accurate geological identification of morphological features. The Magellan mission will map over 70% of Venus at a radar resolution better than 270 meters, which will allow identification and interpretation of most of the major topographic and geological features.

Absolute determination of planetary surface age requires radioisotopic (mass spectrometric) dating of rock samples in Earth-based laboratories or by robotic instruments. Lacking such actual rock samples, surface age and geologic history can be estimated if the planet is imaged at sufficient resolution. Age may be estimated from meteor crater density statistics, and geologic history may be inferred from characteristic surface features and internal mass distributions of the planet itself. The Magellan radar imagery will allow analysis of crater density statistics, while the gravity measurements will show internal mass distributions.

Analysis of the geology of Venus will reveal much about the planet's history. It may be possible to determine from solid body geology when the Venusian atmosphere entered its present extremely dense phase. The identification of possible flow channels and/or basins in the geologic map of Venus will suggest the amounts of water present on Venus in the past, and perhaps when that water was present.

On the Earth, plate tectonics produces readily identifiable geologic features. Data from the Pioneer Venus Orbiter suggests a rough similarity to such features, perhaps extending to the presence of Earthlike "mid-ocean ridge" structural features. However, the available data lacks the resolution to discriminate these possible features definitively. Magellan imagery may settle this question.

Fundamental studies of the origins of the Venusian highlands will use data from all of the Magellan experiments: radar imaging, radiometry, altimetry, and gravity. Imaging will show geologic features indicative of the types of processes, for example folding and faulting, associated with the origin of the highlands. Radiometry will detect the differences in passive microwave emissions from the surface indicative of differing surface texture due to the age, origins, and types of surface material. Altimetry will measure the shapes of the large-scale features. The gravity experiment will provide measurements of mass excesses or deficits associated with the features. All of these observations can be interwoven to test models for the origin of the highlands and the mechanisms whereby their altitude is maintained. Understanding these mechanisms will greatly assist in understanding the ways that heat is transported from the interior of Venus.

The scientific results from Magellan will greatly improve our understanding of the geology of Venus. Such knowledge will directly benefit our understanding of our own Earth. We will be able to compare Earth and Venus by modeling interior processes of both planets. This knowledge of the structure and history of Venus will advance our understanding of the overall evolution of the solar system.

SPACECRAFT FLIGHT SYSTEM

Spacecraft System

Figure 1 shows the Magellan spacecraft in cruise configuration. The spacecraft length is approximately 6.4 m, and the solar panels span about 9.2 m. The spacecraft injected mass into Venus transfer orbit is 3449 kg.

The Magellan spacecraft is composed of structure, thermal control, power, attitude control, propulsion, command data and data storage, and telecommunications subsystems. It has been built as much as possible from flight spares from other programs. These include the electrical power inverters, preregulator, power distribution unit, command data system, and attitude control system computer--all flight spares from Galileo. The spacecraft bus, high-gain antenna (HGA), and low-power thrusters are flight spares from the Voyager program. The medium-gain antenna (MGA) comes from the Mariner series, while the low-gain antenna (LGA) is a Viking flight spare. The large hydrazine thrusters are from the Skylab project, and the hydrazine tank is based on the Shuttle APU tank. The traveling wave tube amplifiers (TWTAs) are from the International Solar Polar Mission. The STAR-48B solid rocket is a standard PAM-D motor.

The Magellan spacecraft was built by the Martin Marietta Astronautics Group (MMAG), Denver, Colorado. MMAG was responsible for system testing and spacecraft processing at Kennedy Space Center in preparation for launch.

Structure

The spacecraft structure is composed of five major sections: the HGA, the forward equipment module (FEM), the spacecraft bus (including the solar array), the propulsion module, and the orbit insertion stage. A functional block diagram of the spacecraft is presented in Figure 2. The HGA is used for the radar sensor and as the primary antenna for the telecommunications system. The FEM contains the radar sensor electronics, the reaction wheels, batteries, and various spacecraft subsystem components.

The spacecraft bus is a ten-sided structure that contains the remainder of the spacecraft subsystem components, including the solar panel array; star scanner; MGA; and the command, data, and data storage (CDDS) subsystem.

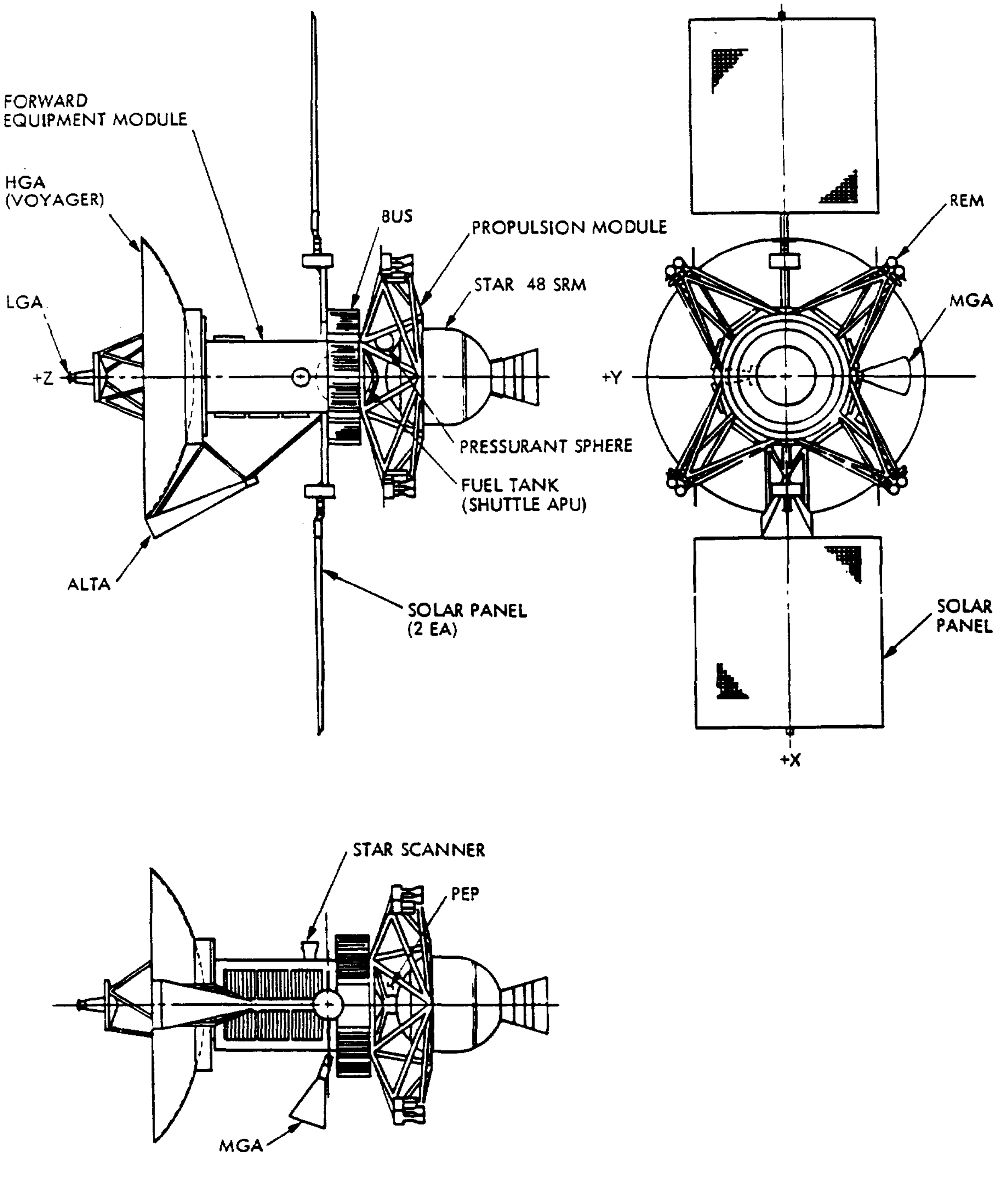


Figure 1. MGN Spacecraft Major Components

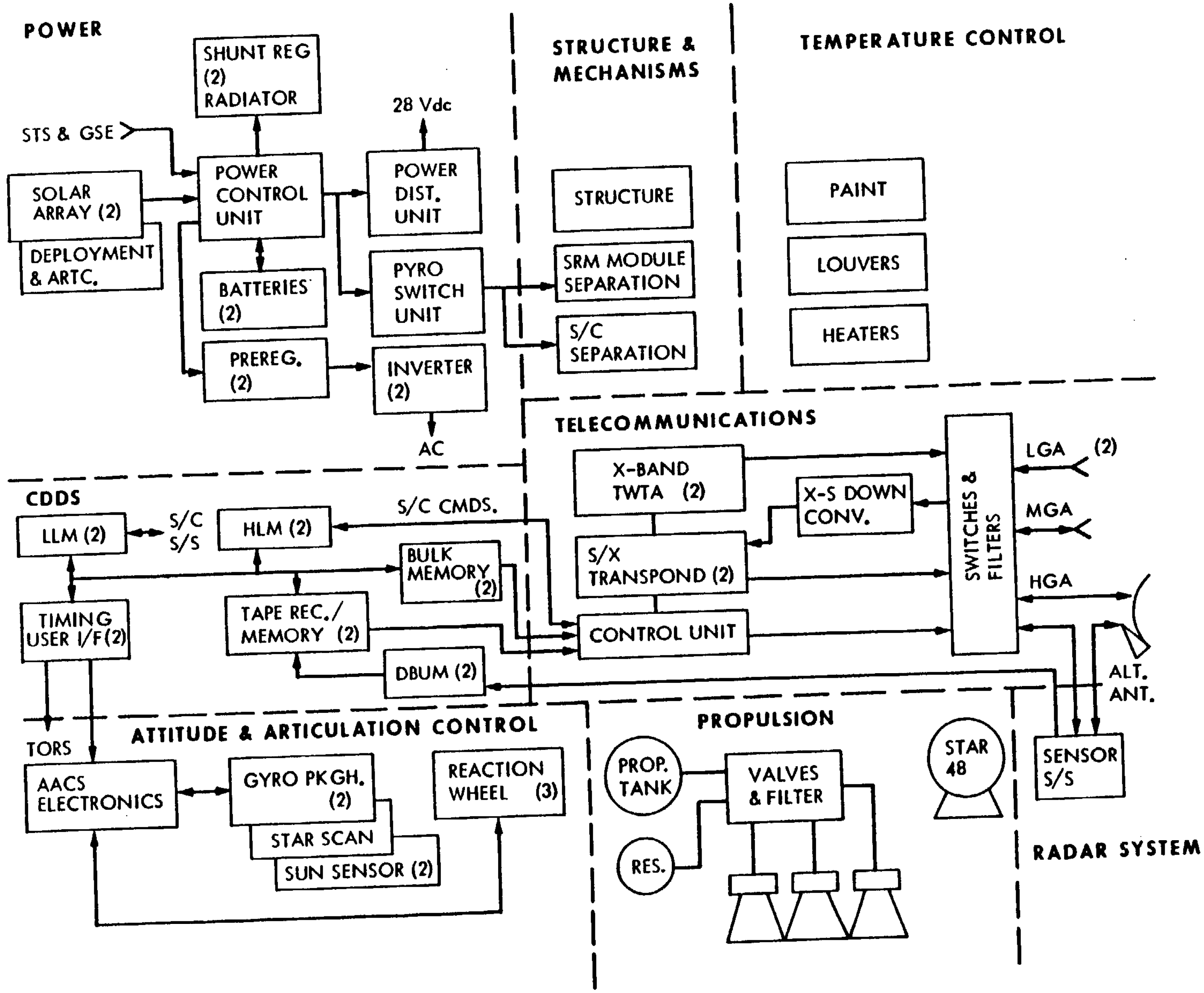


Figure 2. SFS Functional Block Diagram

Thermal Control

Thermal control is accomplished by a combination of louvers, thermal blankets, passive coatings, and heat-dissipating elements. The nominal operating temperature range for spacecraft components is between -5 and +40 °C. The thermal control subsystem maintains these components at the appropriate temperatures for planned orientations of the spacecraft orbit and sun-line and for all spacecraft operating modes.

Power

Power for the spacecraft and the radar sensor is provided by two solar panels with a total area of 12.6 m^2. This array is capable of producing more than 1029 W at the end of the nominal mission, and can rotate about a single axis to track the Sun despite the changing Earth-Sun-spacecraft geometry during the mission. Bus voltage regulation by the power control unit (PCU) uses a shunt regulator to divert excess power from the solar arrays. Two 30 amp-hour nickel cadmium batteries charged from the solar arrays maintain 28 volt power during solar occultation to allow normal spacecraft operations. These batteries are sized and protected so as to allow a degraded mission in the event that one of them fails.

Attitude Control

Spacecraft attitude is controlled by reaction wheels, with monopropellant rocket motors used periodically to desaturate the reaction wheels. During both the interplanetary cruise and Venus orbital portions of the mission, attitude reference will be provided by an inertial reference unit (IRU) updated using celestial references. While performing mapping, the spacecraft is oriented with the HGA pointing toward Venus, and the exact spacecraft attitude varies with spacecraft altitude. After collecting each orbit's mapping data, the spacecraft will be reoriented so that the HGA points toward Earth for transmission of the acquired data.

The spacecraft is capable of pointing the HGA to any desired attitude with a precision of +/- 0.13°. The MGA is attached to the bus just behind the HGA and can be aimed at the Earth when the HGA must be pointed off the Earth-line. The LGA is mounted coaxially with the HGA and does not require precise pointing since it has an omnidirectional beam pattern. The altimeter horn mounting ensures that the narrow aspect of its fan beam pattern is directed to within 0.5° of the nadir when the spacecraft is in a mapping orientation.

Magellan is capable of detecting and responding autonomously to faults or the loss or delay of commands from the ground. The spacecraft is programmed to automatically switch to a "safe" mode, in which the attitude is oriented so as to maintain solar power and orient the antennas toward Earth to await further commands. This automatic safing minimizes the danger of loss of control of the spacecraft.

Propulsion

The propulsion subsystem consists of two parts. The first, a STAR-48B Solid Rocket Motor (SRM), provides the impulse for Venus Orbit Insertion (VOI). Subsequently, the empty casing and parts of its support structure are separated from the spacecraft. The second part consists of monopropellant hydrazine thrusters used for trajectory correction maneuvers (TCMs) during interplanetary cruise, thrust vector control (TVC) during VOI, orbit trim maneuvers during the mapping mission, and reaction wheels desaturation. The hydrazine thrusters are clustered in modules on the end of four outrigger booms.

At each of the four outboard tips of the propulsion structure are clusters of six thrusters: two 445-N, one 22-N, and three 0.9-N. The large motors, aimed aft, are used for steering during midflight course corrections and the VOI maneuver. The 22-N motors, aimed sideways to Magellan's centerline, stabilize the spacecraft from rolling during the same maneuvers. For the duration of the mapping mission, the tiny 0.9-N motors provide thrust to desaturate the momentum wheels and can be used for attitude control, if required. Eight point aft and four are aimed for roll control.

Command Data and Data Storage

The command, data, and data storage (CDDS) system receives uplink commands via the radio frequency subsystem (RFS) and controls the spacecraft in response to those commands. It also controls the acquisition and storage of scientific data and sends it, together with engineering data, to the RFS for transmission to Earth. While in Venus orbit, commands are stored for up to 3 days of radar operation. Provision also exists to receive and execute discrete commands. Engineering data are nominally transmitted to Earth in real-time by the S-band link. When real-time transmission is not possible, due to attitude control system calibration maneuvers or radar mapping operations, the data are tape-recorded and then replayed via the X-band high-rate link.

Magellan is a highly programmable spacecraft, and the control computer system is redundant. This permits both reprogramming of the spacecraft control software and automatic or commanded change to the backup system. The control system includes extensive fault protection capabilities to minimize the danger of loss of spacecraft control.

Both radar data and engineering are nominally stored on two redundant multi-track digital tape recorders (DTRs) for later playback over the high-rate X-band link. No provision exists for real-time transmission of the sensor data, since radar operation reorients the spacecraft to view Venus rather than Earth and uses the same High Gain Antenna as the communications system. Data storage capacity of the two DTRs is approximately 1.8 gigabits. These DTRs are used primarily for recording radar sensor data, although low-rate engineering data is also interleaved with the sensor data, when it cannot be transmitted to Earth in real-time. The recorded data stream is switched alternately between the two DTRs with some overlap so that data is not lost during the changeover.

Telecommunications

The telecommunications subsystem includes the RFS, LGA, MGA, and HGA. The RFS provides carrier transponding, command detection and decoding, and telemetry modulation. The spacecraft is capable of simultaneous coherent X-band and S-band uplink and downlink operation. The S-band link operates with a transmitter power of 5 W, while the X-band link uses 22 W.

Uplink data rates to the spacecraft are 7.8 and 62.5 bps, while downlink data rates are 40 bps (emergency only), 1200 bps (real-time engineering data), 115.2 kbps (radar downlink backup), and 268.8 kbps (nominal). Both high- and low-rate downlink transmissions use the 3.7 m parabolic HGA. Low-rate downlink transmissions during interplanetary cruise and the emergency-only downlink use the MGA. Emergency uplink commands are received through the HGA during the mapping mission and through the MGA during interplanetary cruise.

The telecommunications subsystem acts as a phase-coherent frequency transponder for precise tracking. As long as the Earth to satellite path is sufficiently removed from the Sun, the nominal telecommunications mode uses S-band uplink and simultaneous S- and X-band downlink. When the Earth-to-satellite path comes within 10° of the Sun, X-band uplink and downlink are used. Both the S- and X-band links are used for precise spacecraft tracking.

Radar Sensor

Radar can penetrate Venus's clouds to image the planet's surface. In order to obtain useful resolution of the planet's surface, a radar requires a very narrow effective beamwidth, which implies a very large antenna. Synthetic aperture radar (SAR) uses spacecraft motion to create a synthetic aperture corresponding to an antenna length many times the real length. The Magellan Radar Sensor operates as a SAR at a frequency in S-band (2.385 GHz). SAR data require extensive ground processing to produce images. A digital computer forms each element of the picture by taking into account the time delay, phase, and magnitude of the radar return as the spacecraft moves along its path. The Magellan radar sensor subsystem block diagram is presented in Figure 3.

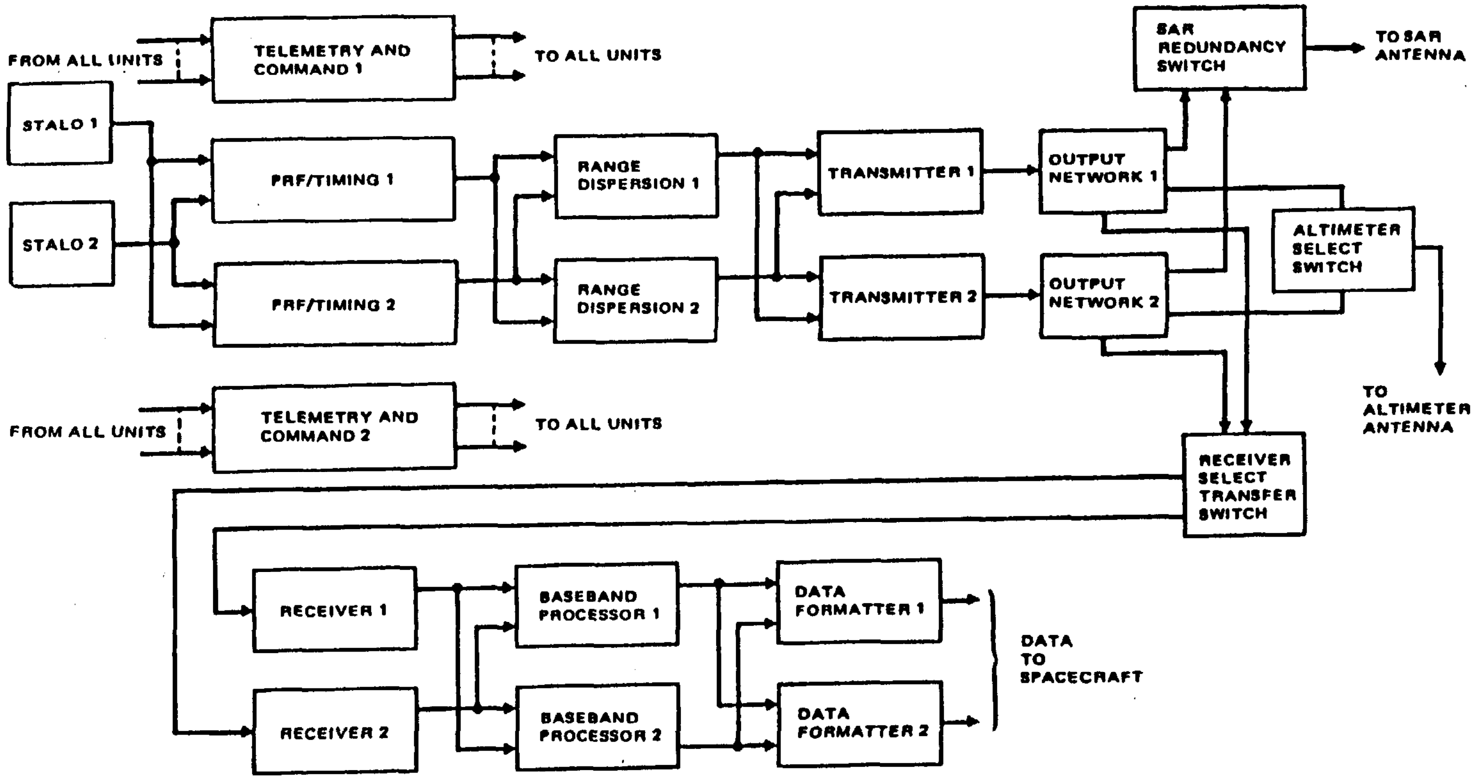


Figure 3. Radar Sensor Subsystem Block Diagram

The Magellan radar system is composed of the radar sensor, HGA and altimeter antenna. The HGA transmits and receives active radar pulses for the SAR mode, and collects microwave energy passively emitted by Venus for the radiometer mode. In the SAR mode, the images have a radar resolution better than 270 m with a minimum of four incoherent looks (to reduce speckle) over an altitude range of 250 to 2100 km. When the radar system operates as a passive radiometer, the temperature resolution is 2° K. As an altimeter, the radar uses a separate fan beam antenna pointed vertically at the planet's surface to measure the heights of geologic features. Magellan altimetry has a vertical resolution of <30 m with a spot size of 20 to 55 km.

In addition to the antennae, the radar comprises a single box of flight hardware containing the following units: a stable local oscillator (STALO), pulse repetition frequency (PRF)/timing, range dispersion, transmitter, output network, receiver, baseband processor, data formatter, and telemetry and command. Each unit is duplicated to provide redundancy which can be switched by ground command. The radar sensor weighs 126 kg.

The STALO provides all timing signals that are distributed from the PRF/timing unit. The range dispersion unit generates a range encoded pulse with a 26.5 msec pulse length using a biphase digital pulse compression code of length 60. This pulse provides a theoretical radar range resolution of 66 meters in slant range, which produces a ground resolution that varies with incidence angle. The transmitter amplifies this encoded signal to 350 W peak power. The output switching network directs the output to either the HGA or the altimeter antenna and returns echoes to the receiver, where they are amplified and filtered to a 10 MHz bandwidth. The radiometer measurements are made at this point. The baseband processor further filters the signal and quantizes it to 8 bits. The data formatter buffers the data, uses a block floating point quantization compression algorithm to represent each data sample as 2 bits, and adds headers with instrument setup and engineering information encoded for tape recording.

Radar sensor operations are controlled by the telemetry and command unit. The radar operates in bursts consisting of SAR, altimeter and radiometer modes in sequence. The burst period varies from 240 to 940 msec, depending on altitude above the planet. Each burst begins with a SAR period of between 25 and 200 msec duration with a PRF from 4400 to 5800 Hz. This is followed by a 1 msec altimeter burst and a 50 msec radiometer passive integration period. The SAR PRF is adjusted so that returning echoes are interleaved with pulse transmission. Altimeter echoes are received after the end of the transmission, allowing simple, non-interleaved reception. The PRF and data-window position for reception of the SAR echoes are precisely controlled by commands from the command unit. These commands use predicted altitude as a function of time from the measured spacecraft orbit and are uplinked to the spacecraft in advance by ground controllers. The characteristics of the Magellan SAR are shown in Table 1.

Table 2 shows the performance of the SAR as a function of altitude. Many of the parameters, such as radar look-angle and burst scheduling, can be altered from the ground while Magellan is in orbit around Venus.

The radar sensor was built by the Space and Communications Group of the Hughes Aircraft Company (HAC), El Segundo, California. Two of the sensor units, the pulse repetition frequency/timing unit and the data formatter unit, were built by the Jet Propulsion Laboratory and delivered to HAC for integration and system-level testing.

Table 1. SAR Characteristics

Nominal Operating Altitude	250-2100 km
Possible Operating Altitude	225-3500 km
Radar Frequency	2.385 GHz
Radar Wavelength	12.6 cm
System Bandwidth	2.26 MHz
Range Resolution	110-270 m
Azimuth Resolution	120-150 m
Number of Looks	4 or more
Swath Width	variable, ~25 km
Antenna Diameter	3.7 m
Antenna Look Angle	14-50° from nadir
Incidence Angle on Surface	19-52°
Polarization	HH
Transmitted Pulse Length	26.5 microsec
Time-Bandwidth Product	60
SAR Data Recorded Bit Rate (on S/C)	750 kbps
Quantization, I x Q	2 bits

Table 2. SAR Performance

Alt, km	Incidence Angle[1], deg	Range Res[2], m	Azimuth Res[2], m	Number of Looks[3]
250	52	110	120	4
276	50	112	120	4
489	39	136	120	6
931	28	182	120	11
1527	20	246	120	12
1751	19	260	120	13
2100	19	270	120	14

[1]The incidence angle is the angle between the radar illumination and the normal to the surface.

[2]The resolution quoted here is the nominal radar resolution, defined as the distance between 3 db points of the radar system impulse function as measured on the surface. The equivalent optical line-pair resolution is approximately two times larger.

[3]Independent observations of a given surface element.

MISSION DESCRIPTION

Overview

The launch system for the Magellan mission combines the Shuttle Orbiter and a 2-stage Inertial Upper Stage (IUS). The orbit geometry from Earth to Venus for the April/May 1989 launch period uses a Type IV interplanetary trajectory with a transfer angle around the Sun of approximately 540° and a cruise period of about 470 days.

The MGN mission can be divided into five distinct phases: launch, cruise, Venus Orbit Insertion (VOI), Venus orbit checkout, and science acquisition.

(1) Launch Phase - from the start of the launch countdown to completion of injection (including separation) from the IUS into the interplanetary transfer trajectory from Earth to Venus.

(2) Cruise Phase - from injection into the Earth-Venus transfer trajectory to 17 days prior to VOI.

(3) Venus Orbit Insertion Phase - from VOI minus 17 days to burnout of the solid rocket insertion motor.

(4) Orbit Trim and Checkout Phase (In-Orbit Checkout) - from burnout of the solid rocket insertion motor to the beginning of the Science Acquisition Phase (18 days).

(5) Science Acquisition Phase - from completion of the Orbit Trim and Checkout Phase to the End of Mission (EOM).

A profile of the Magellan mission, showing dates and durations for the most significant events, is shown in Figure 4. Actual dates and times depend on specific launch date within the 31-day window. Table 3 summarizes the primary mission characteristics. Figure 5 graphically presents the Shuttle and IUS mission events.

Launch

Launch of the MGN/IUS vehicle will be from KSC Complex 39B as flight STS-30 during a 31-day overall launch period opening April 28, 1989, at 18:24 Greenwich Mean Time (GMT) on the Shuttle Orbiter Atlantis (OV-104). The nominal launch period extends through May 24; a contingency launch period continues through May 28. This launch period consists of daily launch opportunities satisfying multiple constraints, including IUS performance, transatlantic Shuttle recovery, and Shuttle yaw steering

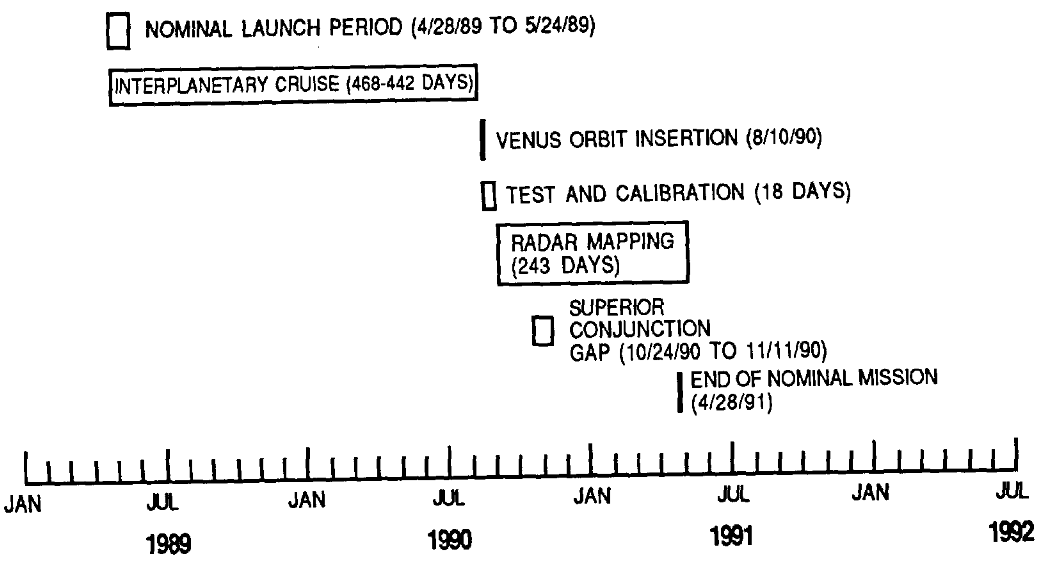


Figure 4. MGN Mission Timeline

Table 3. Characteristics of the MGN Mission

Nominal Launch Period	4/28/89 - 5/24/89
Cruise Duration (w/Pre-VOI Activity)	468 - 442 days
Venus Approach Direction	From North
Venus Longitude of Periapsis at Arrival	276.5° (approximate)
Venus Orbit Insertion (VOI) Date	8/10/90
Duration of In-Orbit Checkout (IOC)	18 days (137 revs)
Mapping Orbit	
Mapping Starts	8/28/90
Period	3.15 hours
Inclination	86°
Periapsis altitude	250 km
Periapsis location	10° N latitude
Superior Conjunction Gap	10/24/90 - 11/11/90
Possible Longitude Coverage Lost	28° (degraded data)
Possible Recovery of SC Gap	6/24/91 - 7/12/91
Occultation of Apoapsis from Earth	
Maximum Duration	57 min
Longitude	149° (approximate)
Days past VOI	127 to 171 days
End of Nominal Mission (end of IOC + 243 days)	4/28/91
End of Project (5 months from EOM)	9/28/91

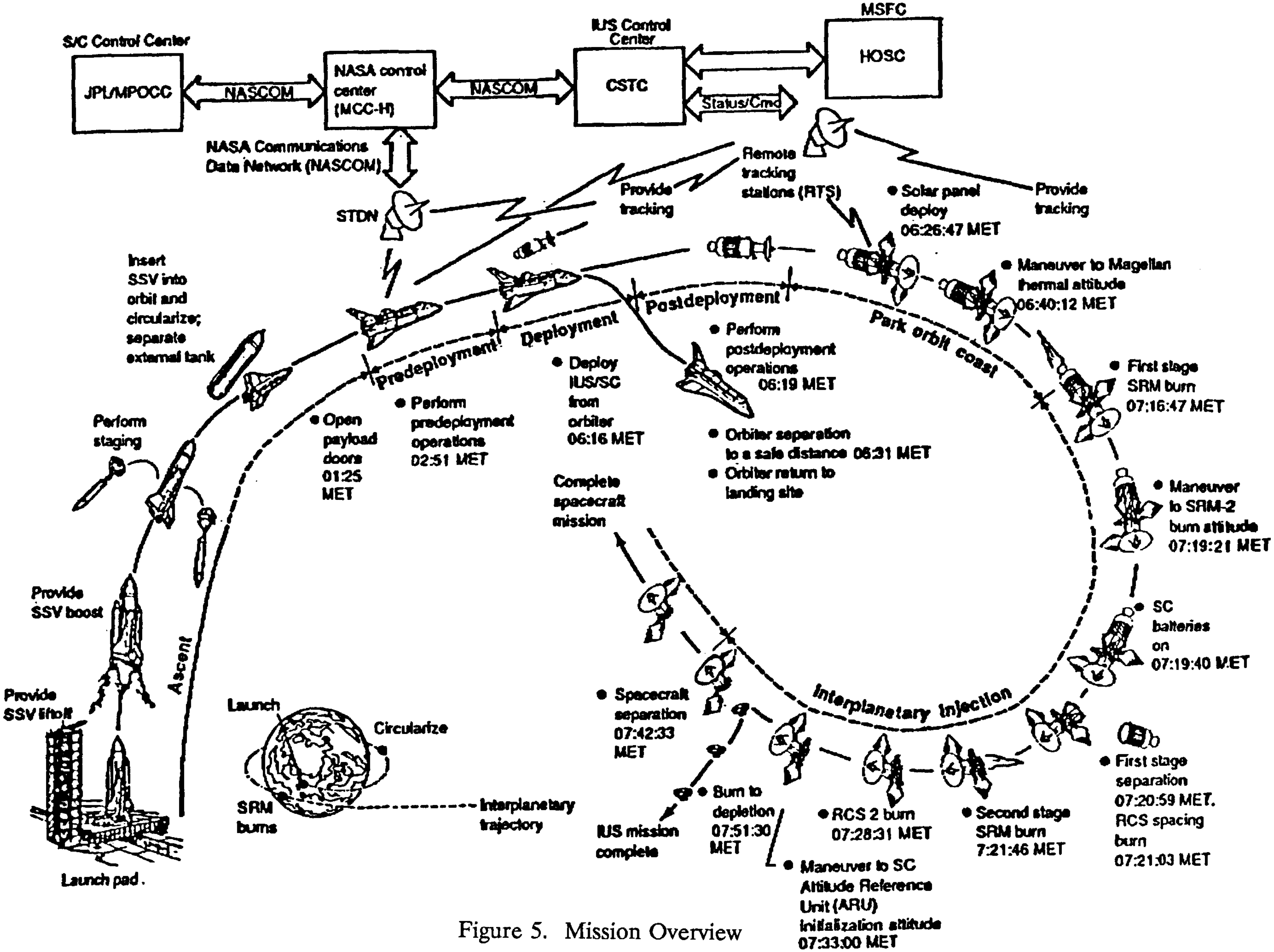


Figure 5. Mission Overview

capability. The Magellan launch window, shown in Figure 6, is defined by contours of open and close time and by the Transatlantic Abort Landing constraint (landing allowed up to 10 minutes past sunset). This launch window is achieved by yaw steering from the Shuttle.

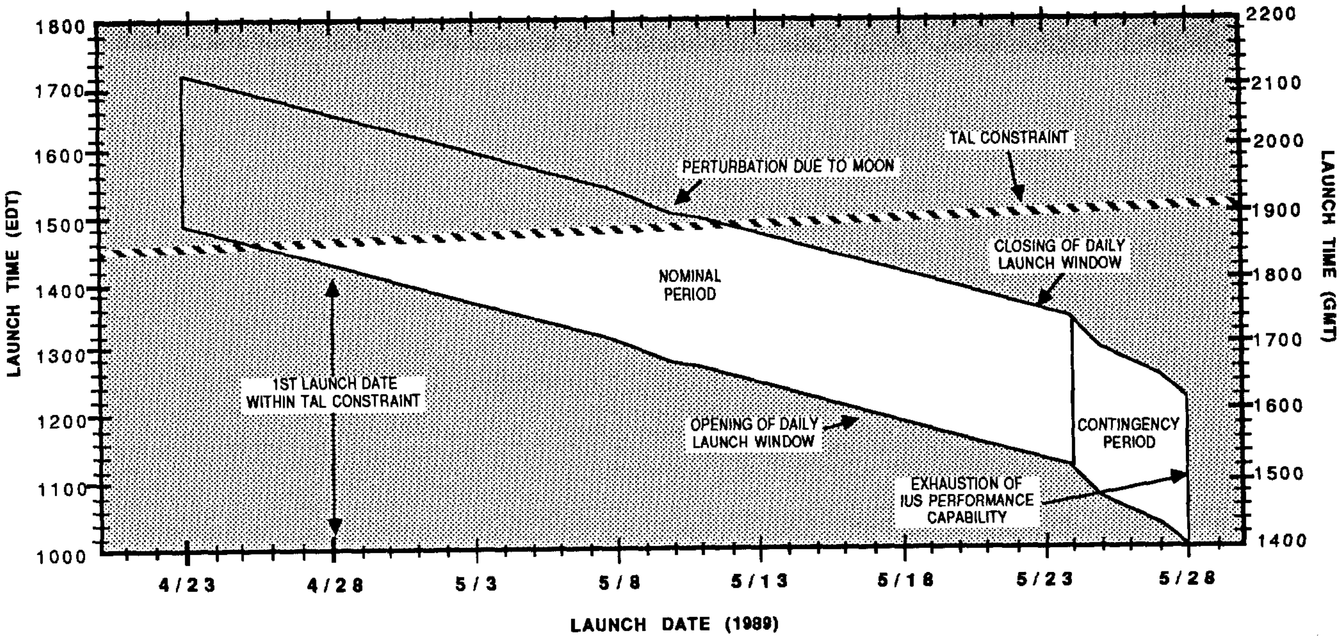


Figure 6. Magellan Launch Window Duration

Figure 7 indicates the range of total payload mass that the IUS could inject into Venus transfer orbit as a function of launch date and injection revolution. The actual injected mass of 3449 kg constrains the overall launch period. The Shuttle uses its yaw steering capability to insert the MGN/IUS vehicle into a parking orbit at an altitude of 296 km and inclination of 28.85°, with the same ascending node independent of launch time within the overall window. The Shuttle parking orbit is illustrated in Figure 8. The STS launch azimuth for this inclination is 85°. Table 4 shows the daily launch window for Magellan through the nominal launch period under the total set of constraints.

The Magellan spacecraft and IUS will nominally be deployed on orbit 5. The Orbiter will initiate a separation sequence 1 minute later using its Reaction Control System (RCS) and Orbital Maneuvering System (OMS) to place the Orbiter in a 327 by 296 km orbit. The nominal MGN/IUS injection burn will occur on orbit 6.

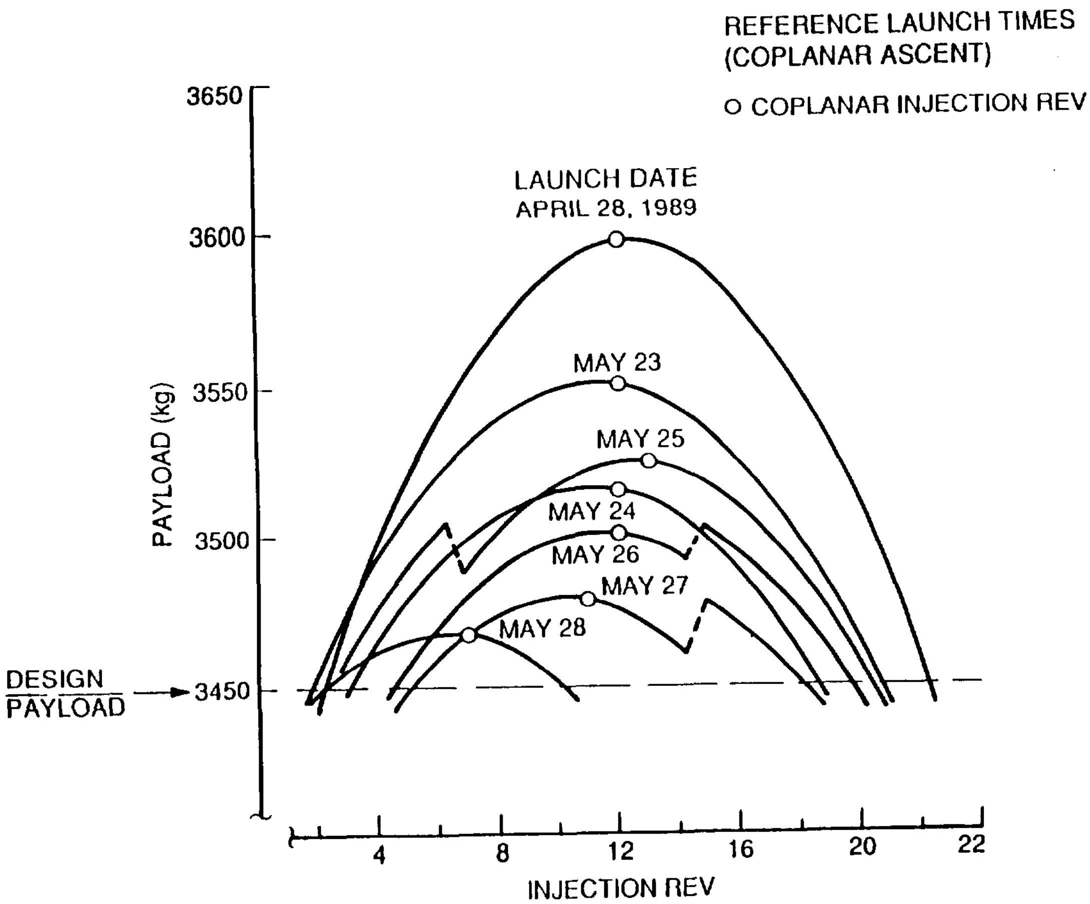


Figure 7. IUS Injection Capability

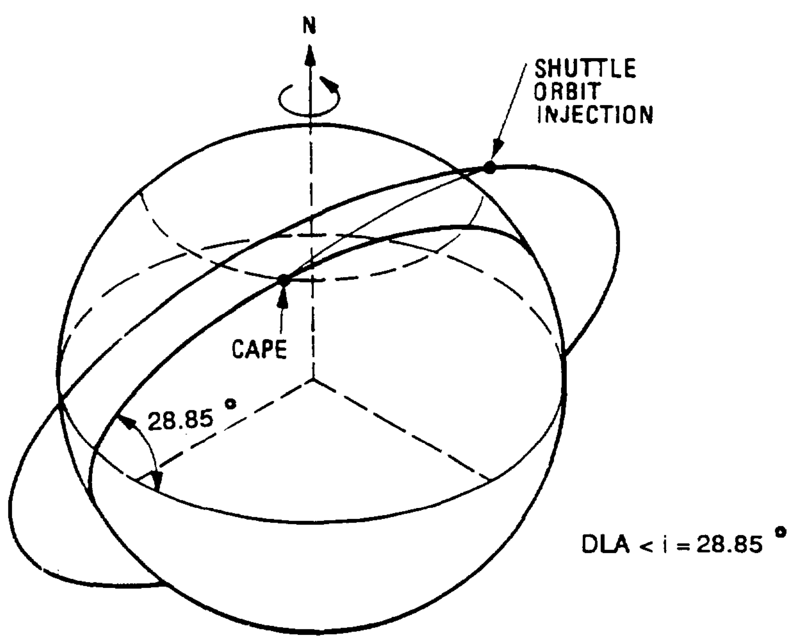


Figure 8. Shuttle Park Orbit Geometry

Table 4. Magellan Launch Window Duration

Eastern Daylight Times

Date	Open	Close	Duration (Minutes)
4/28/1989	2:24 p.m.	2:47 p.m.	23
4/29/1989	2:18	2:43	25
4/30/1989	2:13	2:44	31
5/01/1989	2:07	2:45	38
5/02/1989	2:01	2:45	44
5/03/1989	1:55	2:46	51
5/04/1989	1:48	2:47	59
5/05/1989	1:42	2:48	66
5/06/1989	1:35	2:49	74
5/07/1989	1:29	2:49	80
5/08/1989	1:21	2:50	89
5/09/1989	1:11	2:51	100
5/10/1989	1:02	2:51	109
5/11/1989	12:59	2:52	113
5/12/1989	12:53	2:50	113
5/13/1989	12:46	2:47	121
5/14/1989	12:38	2:39	121
5/15/1989	12:31	2:32	121
5/16/1989	12:23	2:24	121
5/17/1989	12:15	2:16	121
5/18/1989	12:07 p.m.	2:08	121
5/19/1989	11:59 a.m.	2:00	121
5/20/1989	11:50	1:51	121
5/21/1989	11:42	1:43	121
5/22/1989	11:34	1:35	121
5/23/1989	11:25	1:26	121
5/24/1989	11:17	1:18	121
5/25/1989	10:39	12:40	121
5/26/1989	10:29	12:30	121
5/27/1989	10:17	12:18	121
5/28/1989	9:59	12:00 p.m.	121

Figure 9 presents the Nominal Crew Activity Plan for the first 2 days of STS-30 as it relates particularly to Magellan deployment. MGN/IUS backup deployment opportunities are scheduled for orbits 6 and 7 on the first day, and orbits 15, 16, and 17 on the second day. Other possible deployment opportunities occur during scheduled Shuttle crew sleep periods and are considered contingency deployment times.

Figure 10 is a mercator plot of the spacecraft ground track for the nominal and backup injections for a launch date at the beginning of the overall launch period. It shows IUS solid rocket motor 2 burnout and the location of the IUS-spacecraft separation event (SRM 2 burnout + 19 min). Tracking and Data Relay Satellite System (TDRSS) zones of exclusion and DSN horizons for the Shuttle 160-nm parking orbit are also identified. Real-time telemetry coverage of IUS-MGN separation will be provided by the Goddard Space Tracking Data Network (GSTDN) stations at Guam and Merritt Island, Florida (MILA). Figure 11 shows the major events during Magellan's injection into the Venus transfer orbit.

Cruise

Magellan will arrive at Venus on August 10, 1990 at 17:00 GMT independent of the exact launch date and time within the nominal launch period. Cruise time between injection at Earth and arrival at Venus varies from 442 to 468 days, decreasing for injection later in the launch period. This specific arrival time independent of launch date and time enables precise tracking of the events leading to Venus Orbit Insertion by the DSN to be scheduled. The interplanetary trajectory to Venus is shown in Figure 12. This is the first use of a longer sun-circling Type IV trajectory. After separation from the IUS, the spacecraft orbits the Sun approximately 1.6 times before encountering Venus. The MGN spacecraft encounters Venus shortly after its second perihelion passage.

The nominal timeline of spacecraft cruise activities is shown in Figure 13. No radar sensor operations are planned during cruise, but periodic checks and calibration of the gyros, antennae, and communications link will be made. Selected periods of Very Long Baseline Interferometry (VLBI) precision tracking are scheduled during cruise. Three trajectory correction maneuvers (TCM) are planned. The first maneuver (injection+15 days) corrects gross errors from the injection burn, while the second (injection+360 days) refines the transfer orbit. The final TCM (17 days before VOI) adjusts the precise arrival conditions and ends the cruise phase.

Venus Orbit Insertion

Venus arrival at precisely 17:00 GMT on August 10, 1990, (defined by initiation of burn of the STAR-48B SRM) permits simultaneous coverage of pre-VOI burn activities by the Goldstone and Madrid DSN stations. The SRM burn occurs behind

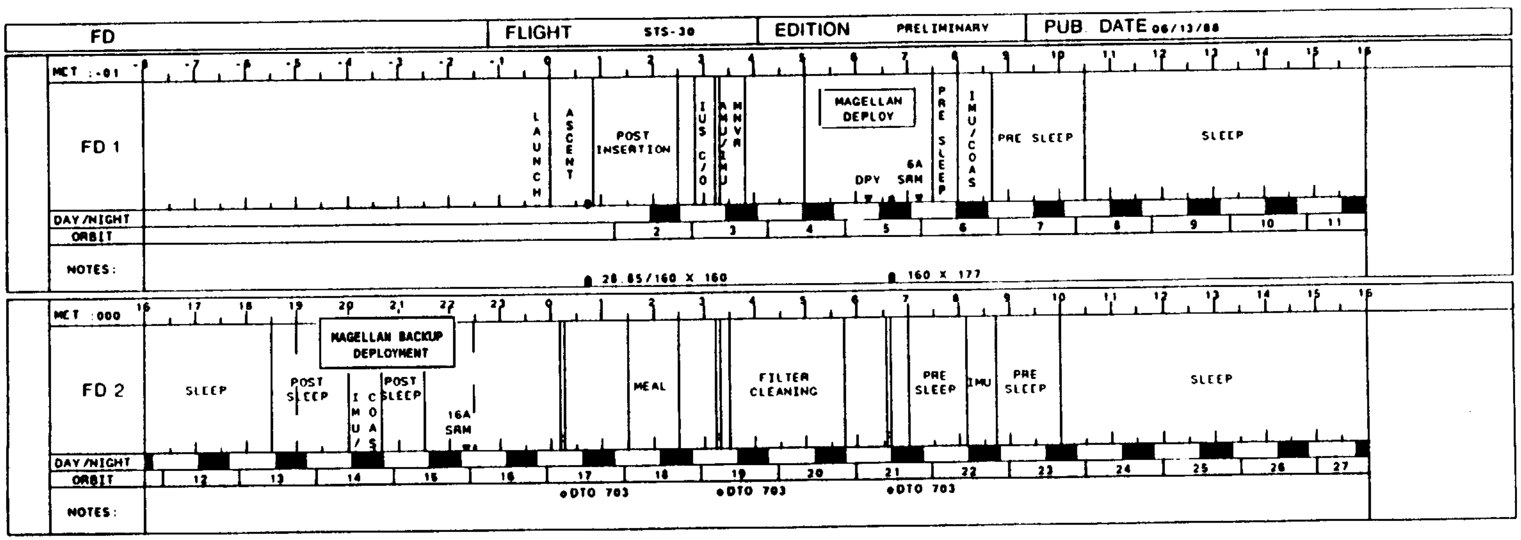


Figure 9. Nominal STS-30 Crew Activity Plan for First 2 Days

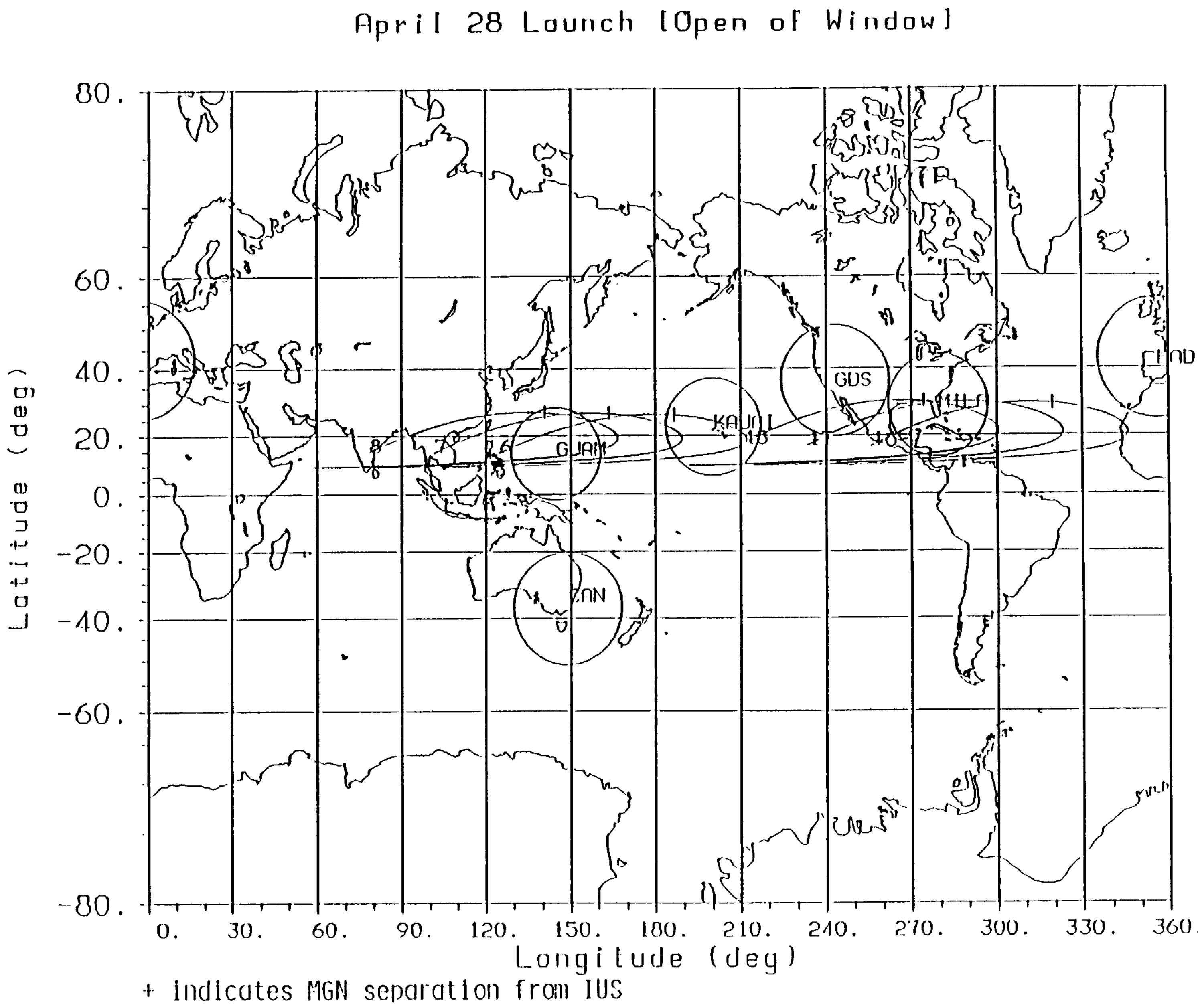


Figure 10. MGN Ground Tracks for First- or Second-Day Injection

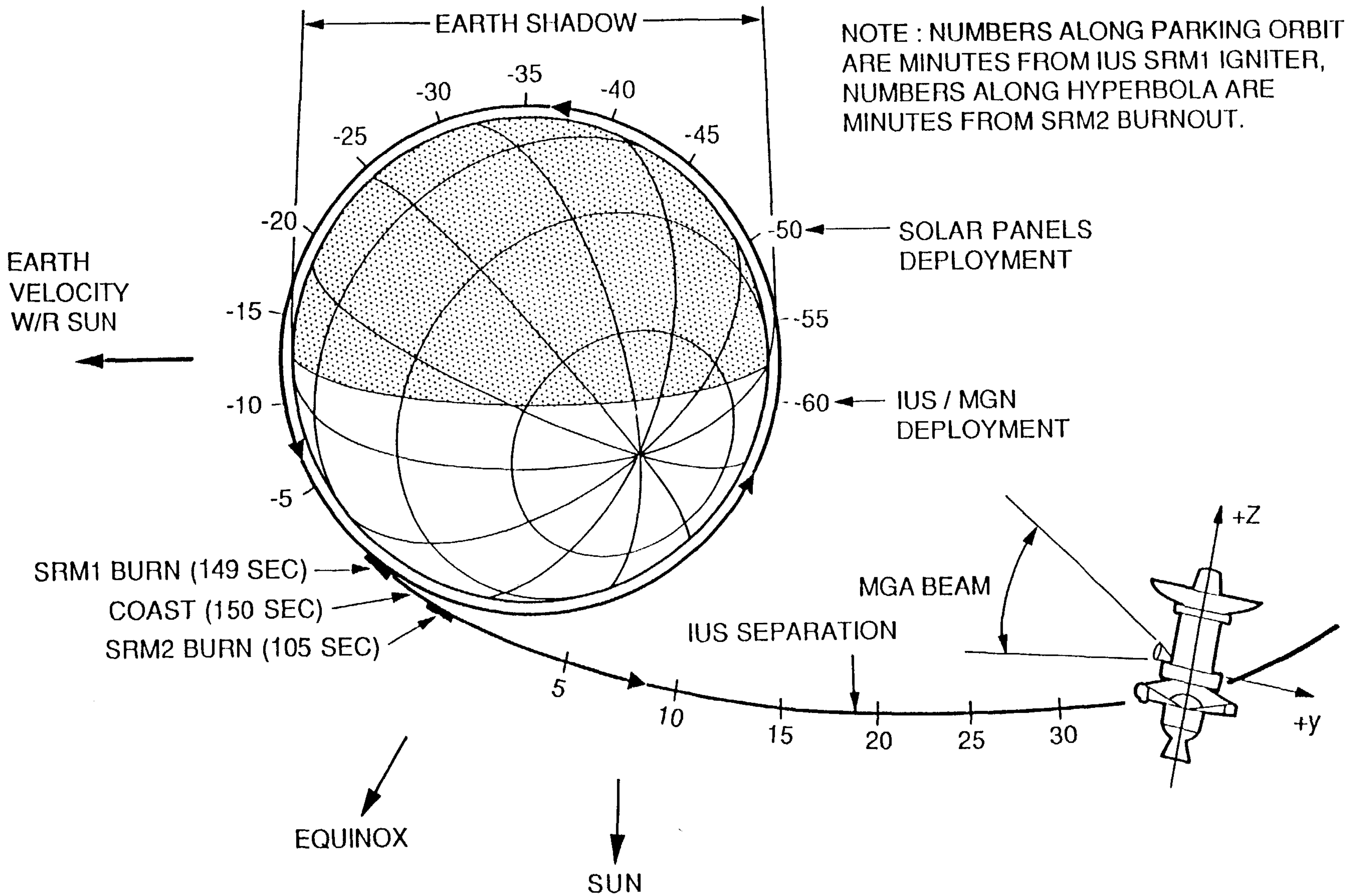


Figure 11. Magellan Near-Earth Major Events

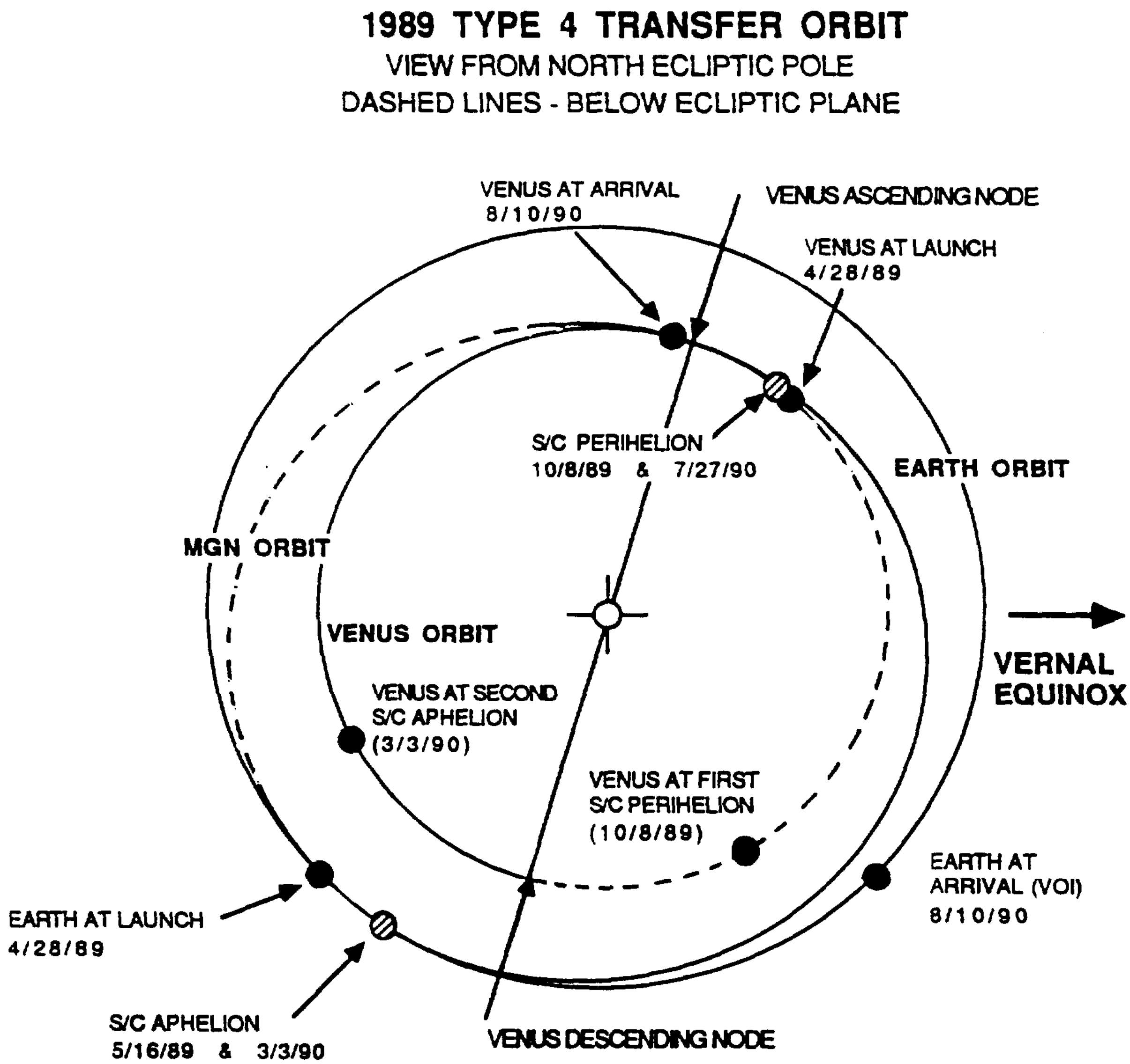


Figure 12. Interesting Events During Cruise

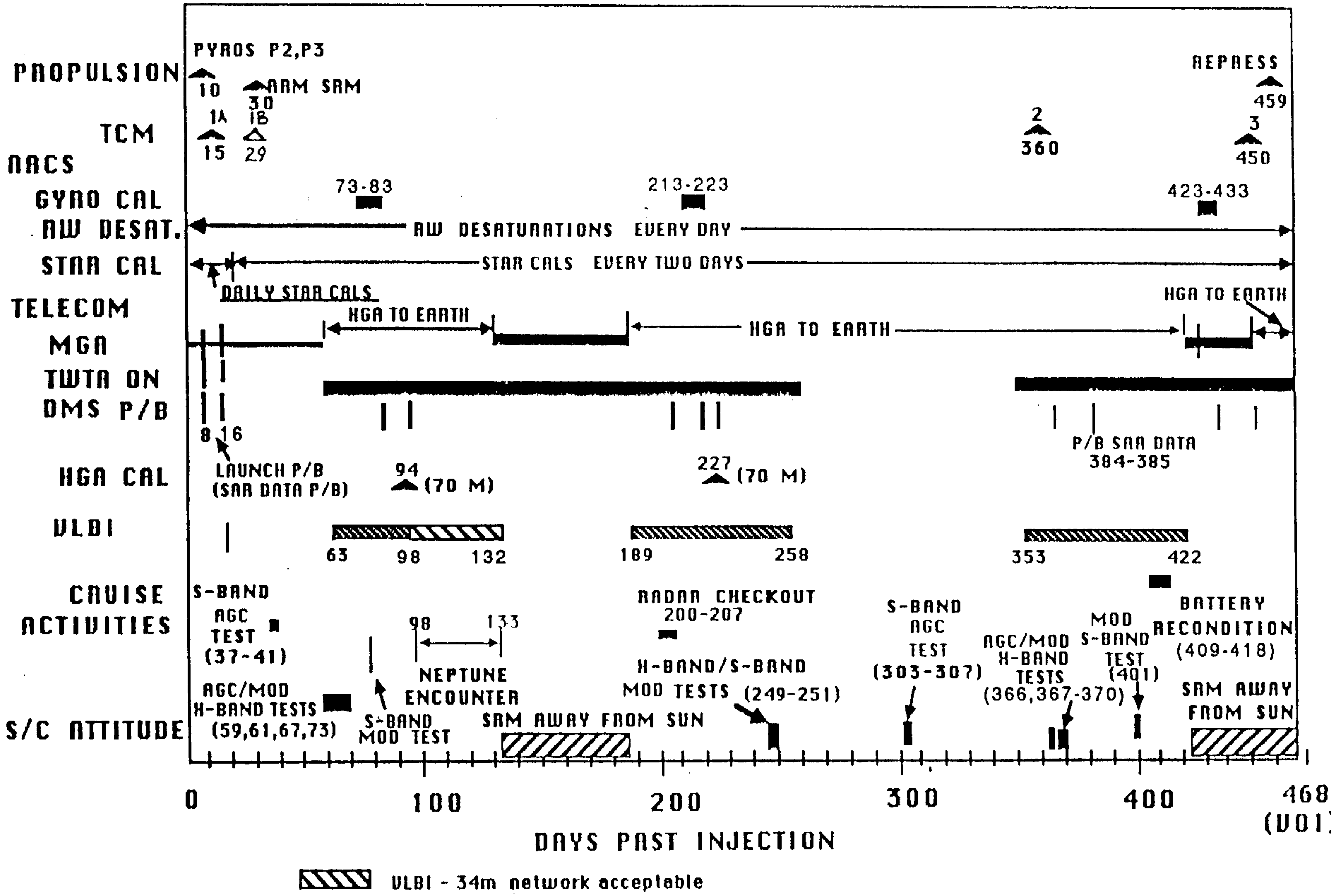


Figure 13. Nominal Cruise Mission Profile

Venus as seen from the Earth. Figures 14 and 15 show the incoming hyperbola and VOI insertion burn as seen from above the orbit plane and as seen from Earth.

The interplanetary transfer orbit to Venus approaches the planet over the north pole. The orbit insertion motor burn is designed to obtain a final mapping orbit with the same node as that of the approach hyperbola. During the science acquisition phase, the mapping pass begins over the north pole and proceeds southward.

An orbit inclined 86° to the Venus equator has been selected for the Magellan mission to provide coverage of the planet's north pole. This coverage was chosen to best complement the previous US and USSR radar mapping of Venus. Periapsis at 10° north latitude was selected to give best resolution in the northern hemisphere. A periapsis altitude of 250 km is low enough to give good SAR resolution with acceptable risk of entering the atmosphere when targeting for VOI. An orbit period of 3.15 hours allows sufficient time to collect and play back the recorded data from each orbit.

The spacecraft is commanded to the VOI attitude 4 hours before SRM firing. The MGA is pointed toward Earth in this attitude to provide a low rate (40 bps) data link until occultation by Venus. Engineering data are recorded during the occultation for later playback. Figure 16 shows the detailed timeline for VOI activities. It indicates the turn to VOI attitude, the initiation of thruster control and magnetic tape recording, the periods of Earth and solar occultation, and their relations with the VOI burn event.

Orbit Trim and Checkout

After VOI, the spacecraft begins an 18 day period of spacecraft and radar sensor checkout and calibration. Two orbital trim maneuvers are planned during this period to precisely adjust the mapping orbit. For the nominal mission, Orbital Trim Maneuver-1 (OTM-1) is planned to adjust the altitude of periapsis and is scheduled for the fifth day after VOI. After OTM-1, the STAR-48B motor case and adapter are separated from the spacecraft by springs. The spacecraft attitude is chosen to avoid recontact with the expended motor case.

The second trim maneuver (OTM-2) is nominally scheduled for VOI plus 12 days and is intended to adjust the final orbital period to 3.15 hours.

Mission and Sensor Control

Mission operations consist of standardized sequences on-board the spacecraft and routine ground operations. The Magellan project provides single-shift staffing for all project teams, with the exception of the Mission Control Team, which is staffed 24 hours per day, 7 days per week.

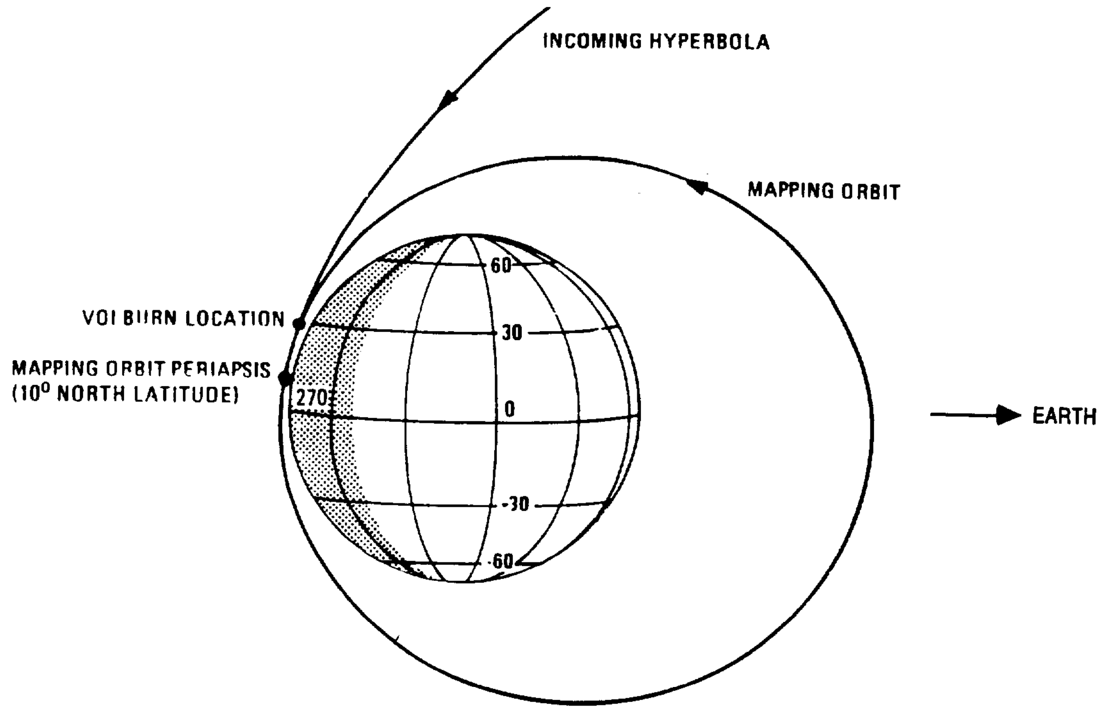


Figure 14. Venus Incoming Hyperbola

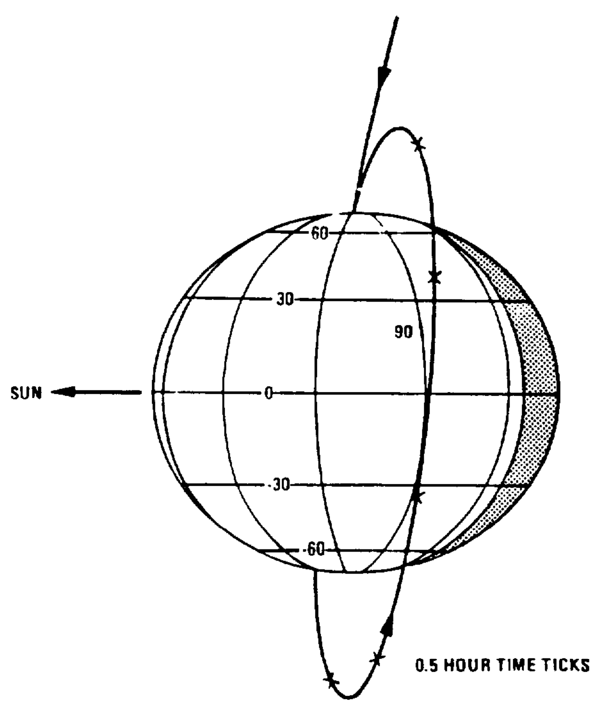


Figure 15. View from Earth (Aug. 10, 1990)

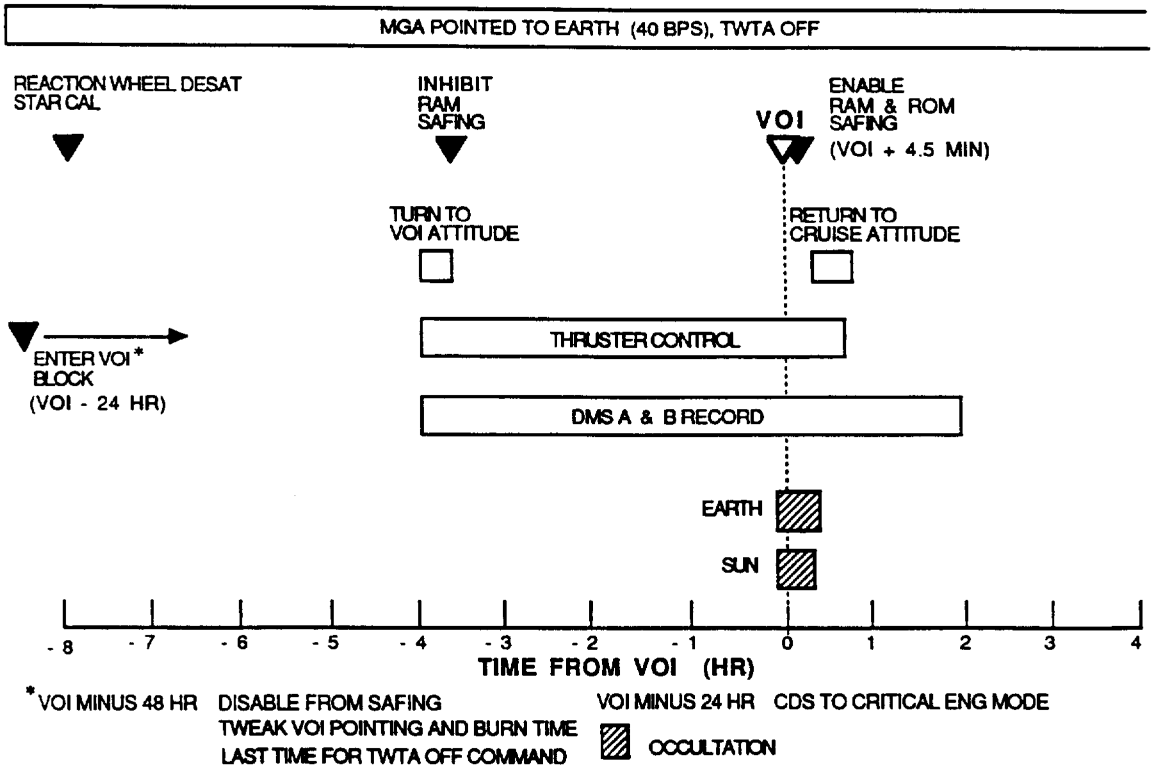


Figure 16. VOI Timeline

Repetitive command sequences for the spacecraft instruments are developed prior to launch. These sequences, with updated parameters, are uplinked to the spacecraft three times per week--on Monday, Tuesday, and Friday. Spacecraft health is monitored through engineering telemetry in real-time and from playback of data recorded during spacecraft maneuvers, mapping, or eclipse when real-time telemetry is not possible.

Fast temporary data products are generated during the mapping mission to check for radar sensor anomalies and to fine-tune the command procedure. Two full consecutive orbits of data are extracted from the Goldstone DSN station data stream each day during the mission. These data are immediately sent to JPL and processed into fast temporary SAR and altimeter data records for engineering analysis. A similar process is applied to the data received at the Canberra and Madrid DSN stations for one full orbit once per week during the mission. These temporary data products are delivered to the operations control team within 1 to 3 regular working days.

Science Acquisition

The orientation of the Magellan mapping orbit remains fixed with respect to inertial space throughout the mapping mission. As the planet rotates beneath the spacecraft orbit, the Venus longitude of periapsis increases by 1.4814° per day. At the end of 243.01 days, periapsis returns to the initial longitude. The relative orientations of the Magellan orbit plane, the Earth-Venus line, and the Venus-Sun line are illustrated in Figure 17. These orientations are critically important to the radar mapping mission, since they determine the spacecraft's ability to map the surface. During the 243 days required to cover the surface, two periods will occur which interrupt the ability to return radar data to Earth: superior conjunction, in which Venus is directly on the opposite side of the Sun from Earth, and a period of eclipse of the Earth by Venus during parts of the time needed to transmit recorded data back. A third period, during which the Sun is eclipsed by Venus for a significant part of the orbit and the total power available from the solar array is therefore reduced, can be accommodated by the spacecraft batteries.

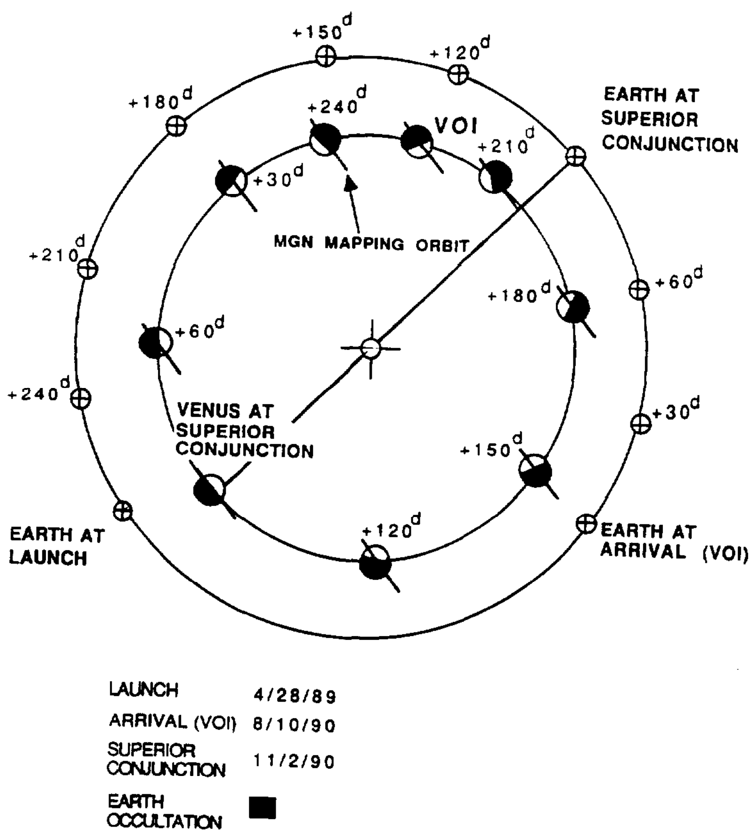


Figure 17. Mapping Orbit Geometry

After Magellan arrives at Venus, the first 18 days in orbit are used for orbit determination, orbit trim maneuvers, and instrument checkout. The mission then begins science data acquisition. Each orbit is divided into a relatively short mapping phase when nearest Venus during which the spacecraft points its radar toward the planet and collects data, and a longer period when further from the planet dedicated to data playback and attitude control system calibration. Mapping activities begin on August 28, 1990, and continue for 243 days (one complete rotation of Venus beneath the spacecraft). The science acquisition timeline is shown in Figure 18.

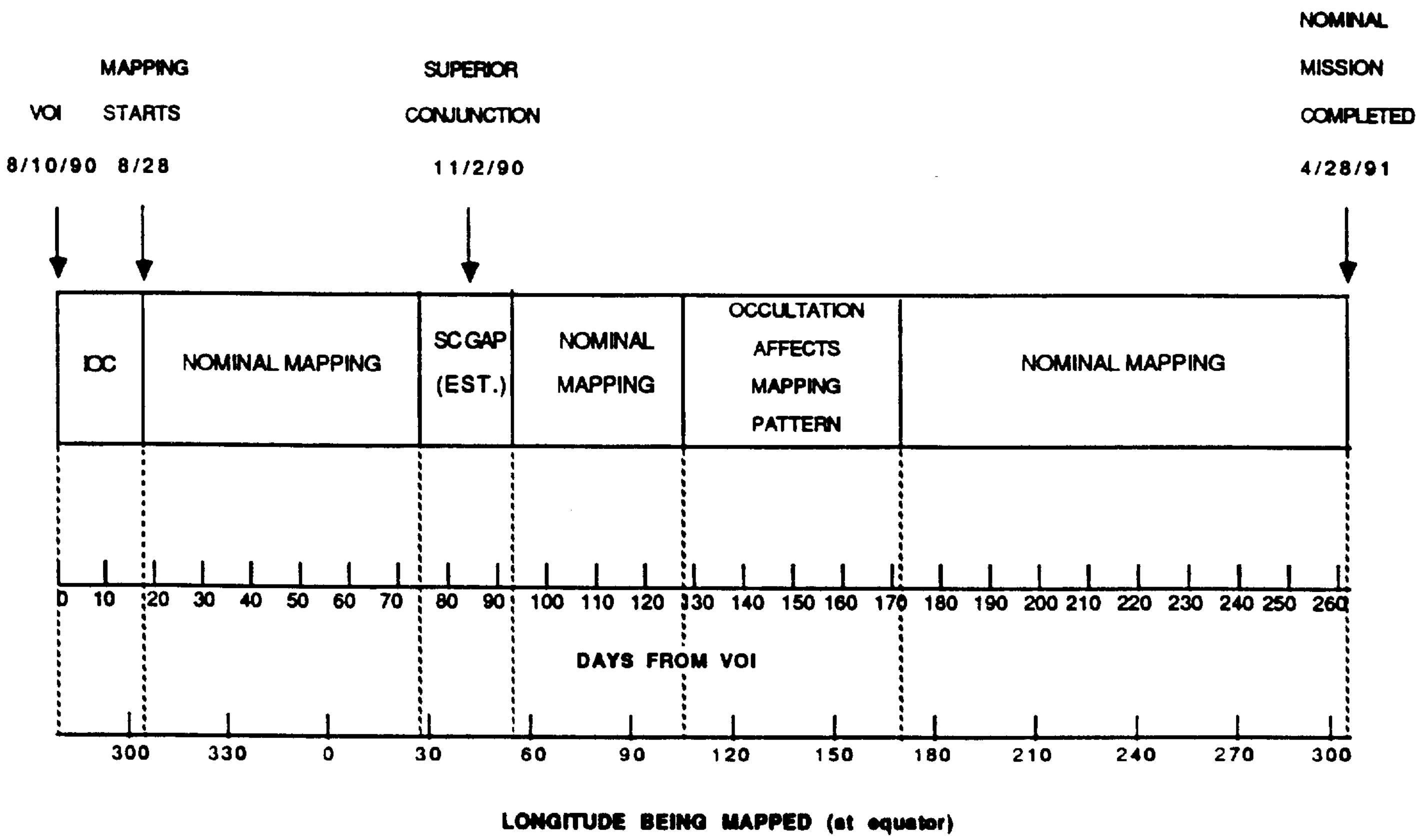


Figure 18. MGN Mapping Timeline

Spacecraft altitude varies substantially during a mapping pass. The SAR illumination is adjusted through a range of look-angles to optimize radar performance for the variable altitude and relative velocities between the spacecraft and the surface. (The look-angle is the angle between the HGA boresight and the spacecraft nadir direction.) Figure 19 shows the look-angle profile as a function of Venus latitude for the left-looking SAR.

The SAR look-angle varies from 13° over the north pole (at an altitude of 2100 km) to 45° at periapsis (250 km) over a latitude of 10° N. Related parameters are shown in Table 5.

Stellar observations are performed prior to apoapsis on every orbit to update the spacecraft attitude control system. This calibration separates two periods of data playback. The spacecraft must turn to a different inertial direction, execute a 90° roll maneuver and turn back toward Earth. The duration of this maneuver varies during the mapping mission. It will be completed within 14 min during the nominal mapping period and within 11 min during periods of Earth occultation.

A summary of SAR mapping characteristics is shown in Table 6.

Mapping Strategies

The nominal strategy for mapping, calibration, and playback activities of the spacecraft has two modes. The primary mode is used when the orbit geometry permits full playback of all recorded data to Earth. The second mode is used when the communication link from apoapsis to Earth is obstructed by Venus. A backup strategy has been developed for occasions when the 268.8 kbps downlink rate cannot be maintained by the DSN.

The nominal mapping strategy collects SAR data in a pattern of alternating swaths. Data taken on even-numbered orbits are biased toward the southern hemisphere, while data gathered on odd-numbered orbits start over the north pole. Data are collected over a latitude range from 90° N to 67.2° S. Figure 20 illustrates the data acquisition and playback schedule during each orbit. The same information is displayed in a timeline format in Figure 21. Note that up to 6 min is allocated for spacecraft turn times.

To simplify the mapping process, the spacecraft follows the same attitude profile on each orbit. The radar also operates over the same portion of each orbit. However, on alternating orbits the parts of the data recorded for return to Earth vary. Northern-biased swaths start the recorders over the north pole and stop approximately 4.7 min before the end of radar operation. Southern-biased swaths start the recorders 4.7 min after passing over the north pole and stop at the end of radar operation.

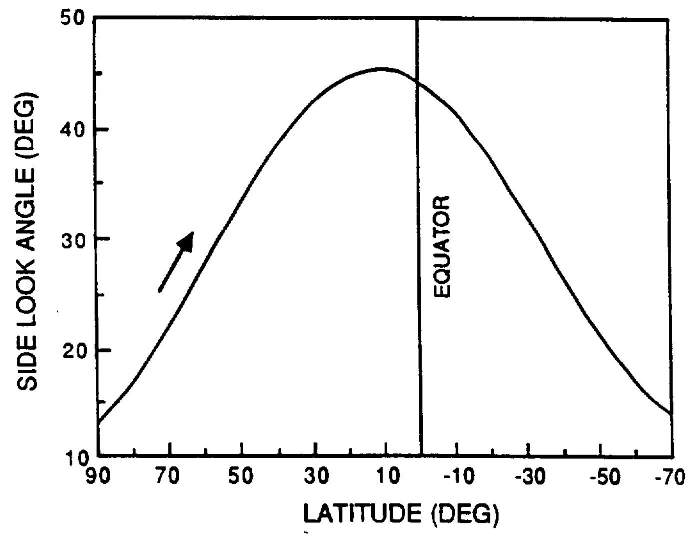


Figure 19. Side Look-Angle vs. Latitude for Left-Looking SAR

Table 5. Nominal Mapping Orbit Parameters

Period	189.0 min 3.15 hr
Periapsis altitude	250.0 km
Apoapsis altitude	8029 km
Venus sidereal period	243.01 days
Rate of rotation	-1.4814 deg/day -0.1944 deg/orbit
Shift in ground track at equator	20.53 km/orbit
Periapsis latitude	10.0 deg
Periapsis longitude at arrival	276.5 deg

Table 6. Summary of Mapping Characteristics

Mapping frequency	1 swath/orbit
SAR data record rate	806.4 kbps
Record duration	37.2 min
Playback rate	268.8 or 115.2 kbps
Nominal playback duration	113.7 min
Tape recorder capacity	3.6×10^9 bits
True anomaly range during mapping	-80 to +80 deg
Altitude range during mapping	250 to 2100 km
Look-angles during mapping	13 to 45 deg
Swath width and length	25 km (variable) by 16,000 km
Duration of mapping mission	243 days, including SC gap
Nominal latitude range of planet mapped	+90 to -67.2 deg
Expected planet coverage (RSS)	79.4 percent
Daily planet coverage	0.4 percent

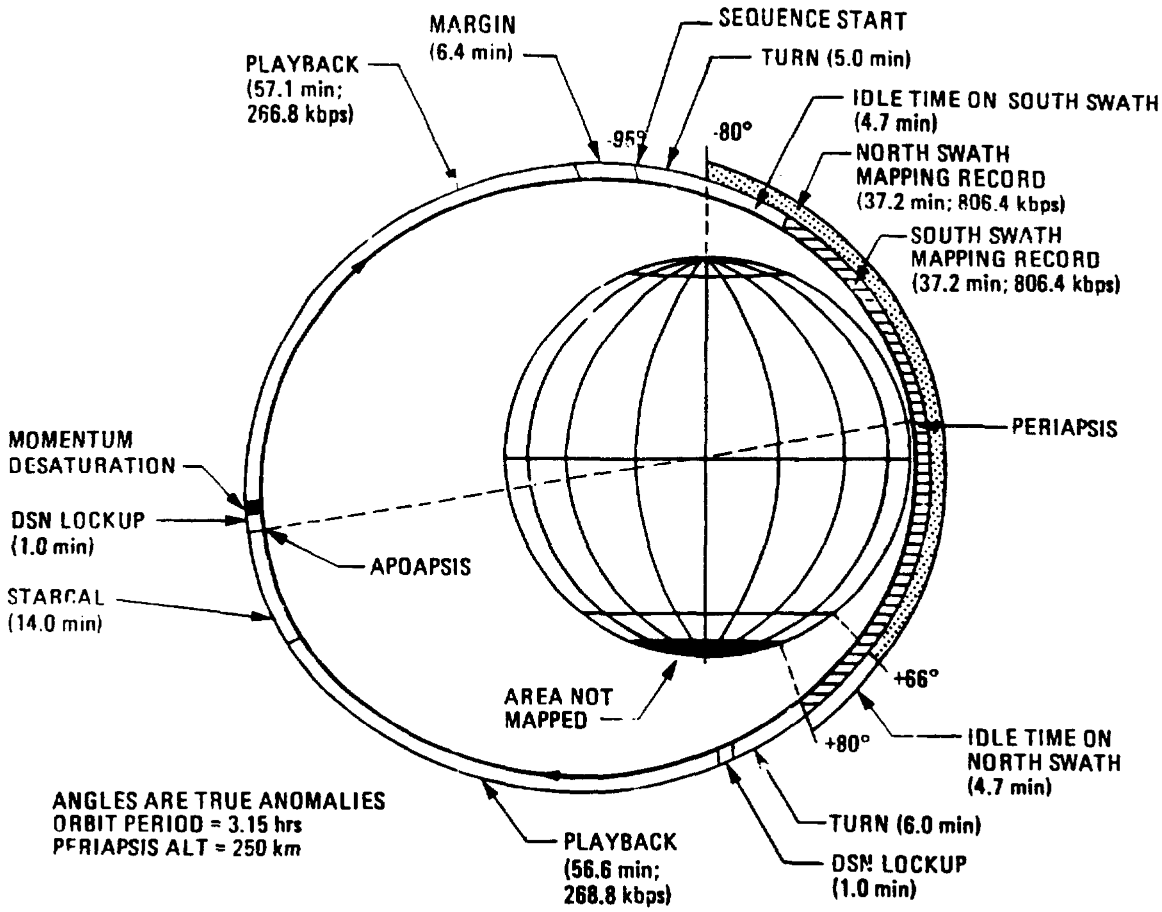


Figure 20. Nominal Mapping Strategy (Alternating Swaths)

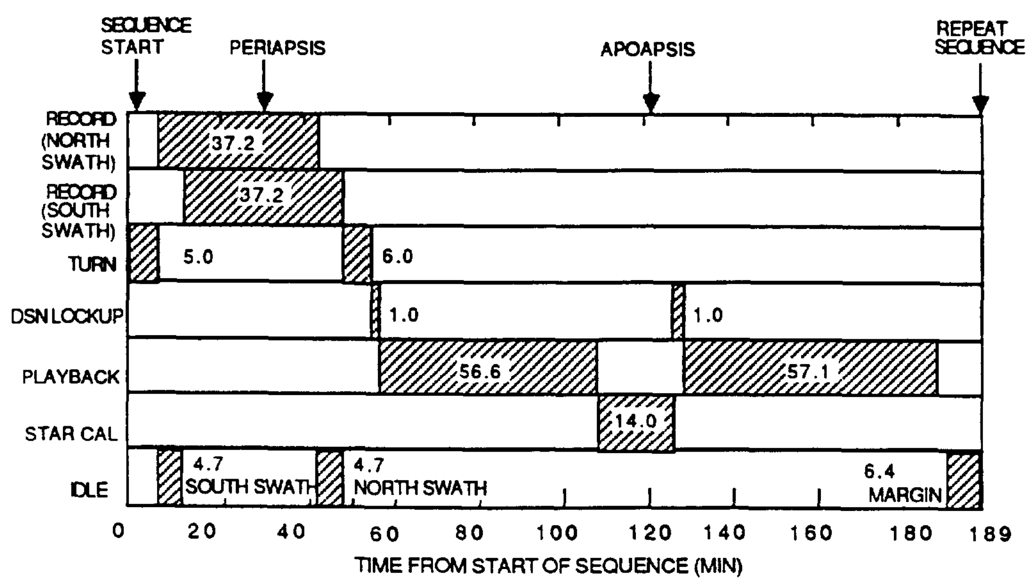


Figure 21. Timeline for Nominal Mapping Strategy (Alternating Swaths)

A total of 37.2 min of radar data is recorded on each orbit. This total is limited by the ability to replay the recorded data at the downlink rate (268.8 kbps) within the orbit period. Some margin is necessary for data overlap between recorders, engineering data, and spacecraft maneuver times.

The pattern of alternately overlapping northern and southern swaths covers most of the planet. Figure 22 shows the overlap between two northern swaths and one southern swath at the start of a southern swath. The minimum swath width of 20 km is wide enough to cause alternating swaths to overlap substantially at high latitudes. Figure 23 shows the overlap at the end of a pair of northern swaths.

Near the equator, adjacent swaths overlap by only 2 km. The swath widths must cover a greater surface area at lower latitudes. The loss of any pass of SAR mapping data leaves a narrow tapered gap in the mapping coverage. No such gaps will occur during the nominal strategy's primary mode.

The secondary mode is necessary during periods when the full time needed for replay of recorded data is not available because of occultation of the Earth-spacecraft path by Venus. Figure 24 shows the change of orbital event schedule to accommodate the limitation on data transmission time.

The spacecraft orbital schedule is determined by the length of the occultation. In the secondary mode swaths no longer alternate, but instead begin at the north pole and extend as far south as possible. The southern extent of mapping is determined by occultation, playback, turn, DSN lock-up, and star calibration time (reduced to only 11 min). For a maximum 57.3-min occultation, approximately 118 minutes remain for data gathering and playback. This results in 28.9 min of mapping data, covering the planet from 90° N to 25° S. The resulting loss in mapping coverage appears in the mercator projection of Venus as a bulge in the unmapped southern polar region centered around 149° longitude.

Superior conjunction of Venus, when the Earth and Venus are on exactly opposite sides of the Sun, occurs on November 2, 1990. For Sun-Earth-Venus angles less than 2.5°, solar interference is expected to seriously degrade the reception of mapping data. This loss of coverage may cover as much as 28° of longitude on the surface of Venus, depending on the actual downlink performance. As the telemetry link degrades past a certain level, mapping activity will be halted and the spacecraft put into a safe state. As soon as the ground team recovers the spacecraft signal, mapping operations will resume.

Mapping coverage for the nominal mission, including the areas lost due to superior conjunction and occultation, is shown in Figures 25 through 27. The bulge in the unmapped southern polar region centered around 149° longitude is a result of the apoapsis eclipses when playback of the recorded sensor data is restricted because Venus blocks the Earth from the spacecraft during the playback period. If an extended mission is possible the areas of Venus not covered during the nominal mission can be mapped.

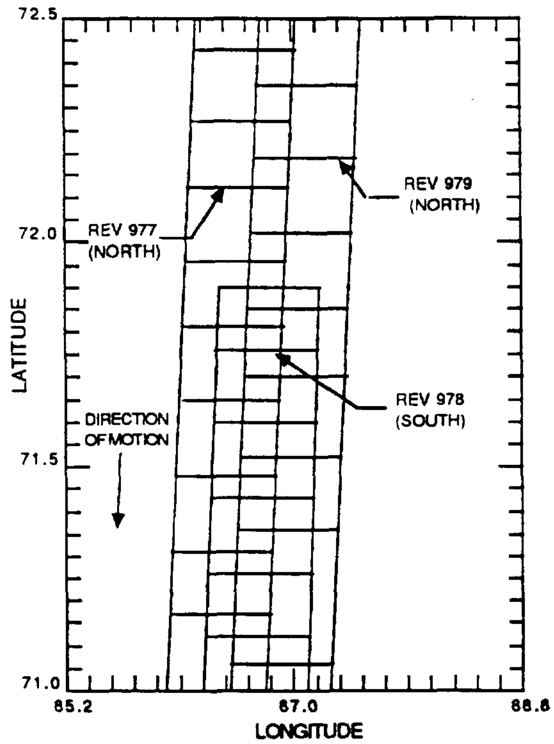


Figure 22. Northern Hemisphere Alternating Swath Overlap

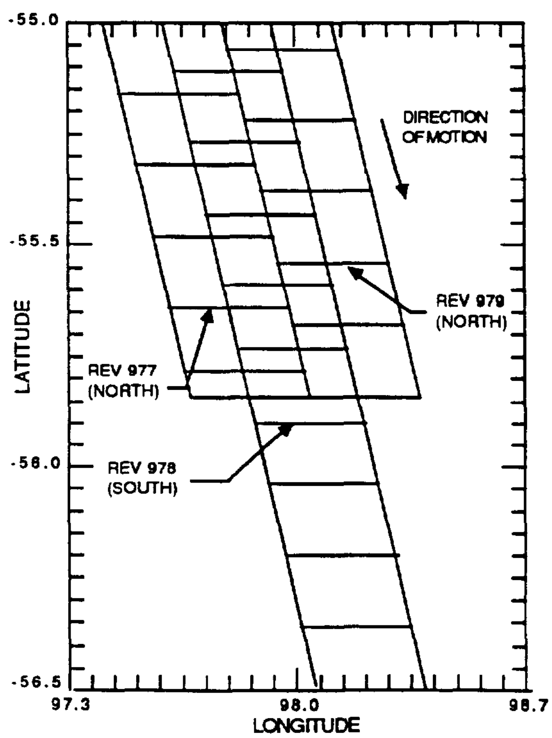


Figure 23. Southern Hemisphere Alternating Swath Overlap

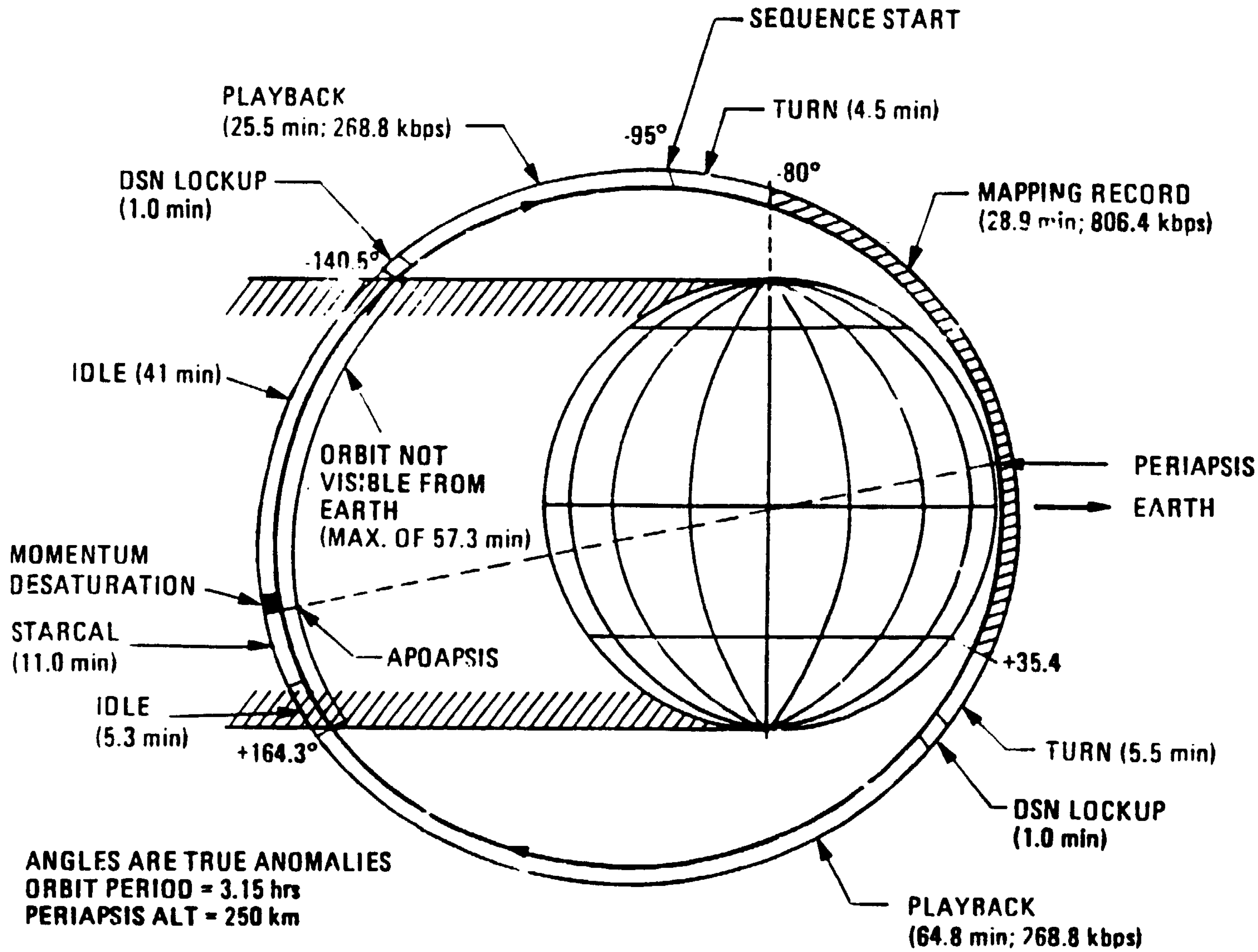


Figure 24. Mapping Strategy During Apoapsis Occultation

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DATA PROCESSING

Magellan ground data processing will be performed within a specialized Radar Data Processing Subsystem (RDPS), which includes the equipment necessary to convert the returned digital data recorded at the tracking stations into imagery from the SAR, topographic measurements from the altimeter, and surface brightness temperatures from the radiometer. SAR data processing is performed within a very fast Advanced Digital SAR Processor designed and built by JPL specifically for this purpose. The high accuracy altimetry and radiometry data processing will be performed at MIT.

Mosaicking of the SAR, altimetry, and radiometry products is done within the Image Data Processing Subsystem. Standard mosaic data products comprise an array of 8 x 7 subframes of 1024 x 1024 pixels. Several pixel spacings are generated for planetary-scale mosaics (225, 675, and 2050 m). The mosaic products will be produced both as digital and photographic (hard copy) material.

The volume of data acquisition planned for the Magellan radar during the 243-day mission--3070 Gb--is enormous in comparison to other planetary missions. This fact necessitates particular attention to mission data processing. The primary data product is a full-resolution, basic image data record (F-BIDR) of one swath of SAR imagery 25 km wide and 16,000 km in length. All SAR data will be processed into F-BIDRs, although photo products will not be produced from these primary data records. The image strips are assembled into geocoded mosaicked frames of 111 km by 550 km with 5 km overlap for tie points. The pixel spacing of these mosaics is equivalent to 75 m on the surface of Venus. A total of 220 full-resolution mosaicked image data record (F-MIDR) frames will be produced. (Note that this represents only 15 percent of the surface of Venus.) The frames will be further assembled into compressed mosaicked image data record (C-MIDR) products at 3 scales showing planetary features over larger areas. Figure 28 displays the F-BIDR swath and the resulting F-MIDR and C1, 2, and 3-MIDR products.

Figure 29 shows the overall data flow for Magellan from the Deep Space Network into the SAR Processing and Multimission Image Processing Laboratories, and subsequently into the Data Management and Archive System. The complete data processing and archive system will provide efficient access to all Magellan data in order to maximize the scientific benefit of the mission.

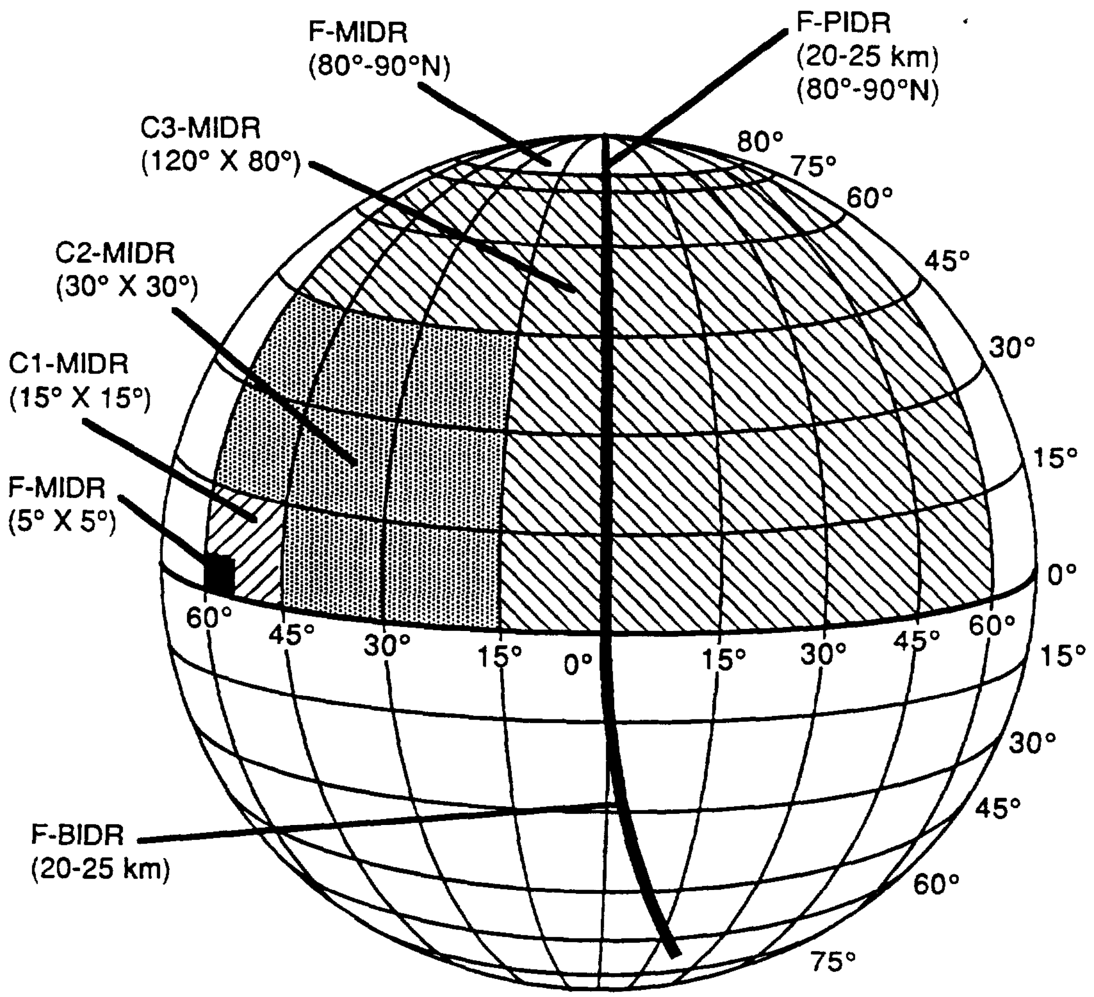

Figure 28. Magellan Image Data Products

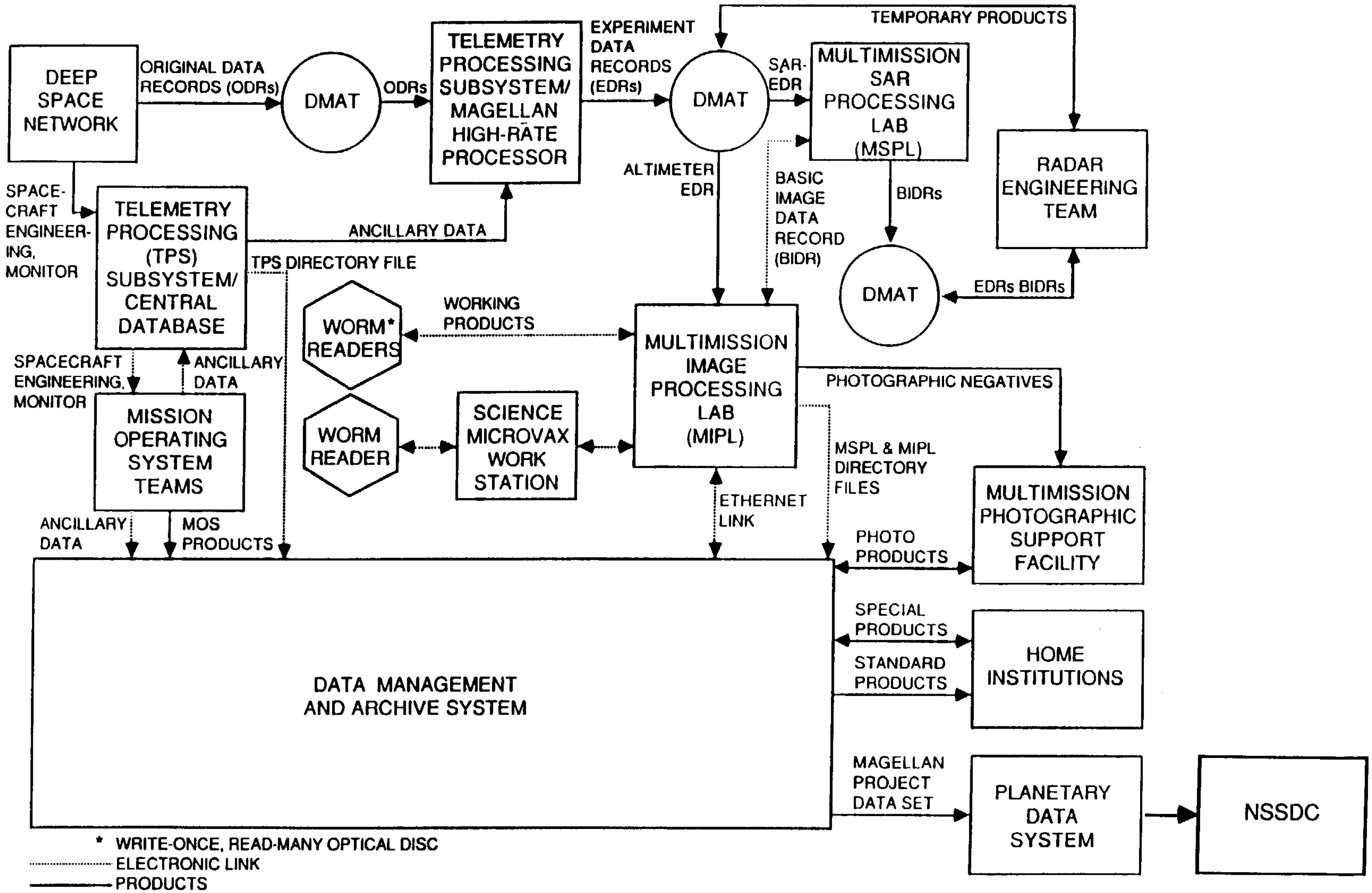

Figure 29. Magellan Data Flow

MISSION SUPPORT

Deep Space Network

NASA's Deep Space Network will provide precision tracking, command and control, telemetry, and science data reception for Magellan.

The DSN consists of 12 stations positioned at three Deep Space Communications Complexes on three continents: Goldstone in Southern California's Mojave Desert; Madrid, Spain; and Canberra, Australia. The three locations are approximately 120 degrees apart in longitude, which allows suitable overlap for continuous observation while transferring the spacecraft radio link from one complex to the next. The Network Operations Control Center, which controls and monitors operations at the three complexes, is located at JPL in Pasadena. The Network's Ground Communications Facility at JPL provides the communications circuits that link the complexes, the control center in Pasadena, and the various remote flight project operations centers. Figure 30 shows the DSN configuration.

Each complex consists of four deep space stations equipped with large parabolic dish antennas. There are two 34-meter diameter antennas, one 26-meter, and one 70-meter. One of the 34-meter antennas at each complex is a high-efficiency antenna to provide improved telemetry performance.

The most significant unique Magellan requirements on DSN affected the Telemetry System; less significant impacts occurred for the Command, Monitor and Control, Test Support, Tracking, and Very Long Baseline Interferometry (VLBI) Systems. DSN will support two unusual types of capabilities for Magellan:

Unique Communications Capabilities

- The ability to simultaneously receive and process two coded downlink channels (one high-rate X-band and one low-rate S- or X-band). The high-rate X-band channel carries recorded radar mapping data and the low-rate S- or X-band channel carries real-time engineering telemetry.

- The ability to transmit uplink command data in X-band at rates of 7.8 and 62.5 b/s, and to switch in near-real time between the two data rates.

DSN Special Support for Magellan

- The ability to acquire telemetry signals, from receiver through frame synchronizer, within one minute.

- The ability to accommodate the high Doppler frequencies associated with Magellan's three-hour orbit.

- Precision navigation, requiring the acquisition of VLBI data from each of two baselines on a daily basis.

Data flow for DSN telemetry is shown in Figure 31. Signals are collected under the control of the Antenna Mechanical Subsystem; amplified by low-noise amplifiers in the Antenna Microwave Subsystem; detected and downconverted by S- and X-band receivers in the Receiver-Exciter Subsystem; demodulated, decoded, and synchronized in the Telemetry Subsystem; and formatted, recorded, and transmitted to the Project via the Ground Communications Facility.

Real-time coverage of IUS-MGN separation will adjust for Shuttle launch time, deployment, and the precise length of the IUS burns. The Magellan downlink transponder will first turn on at SRM-2 burnout plus 12.5 minutes, so the first actual spacecraft signal acquisition occurs at that time. The nominal transponder acquisition will use the MGA, which is fixed in inertial space at IUS-S/C separation. For the nominal mission, Goldstone will acquire Magellan at SRM-2 burnout plus 16 minutes, and will be the principal station to support IUS separation. Non-DSN stations (Guam and MILA) will provide supplementary real-time coverage.

Initial acquisition of Magellan will use the 26-meter subnet. Telemetry will pass through the Signal Processing Center (SPC) at each complex to the Network Operations Control Center (NOCC) at JPL; commands will pass from the SPC to the 26-meter exciter. DSN will cover critical spacecraft events and data return from the mapping mission. Precision tracking at VOI will use 70 m antennae at each DSN site. After VOI, a pair of 34 m antennae at each site provide adequate link margin until shortly before superior conjunction. 70 m coverage is again used, together with a 34 m High Efficiency Frequency (HEF) station for X-band uplink, to minimize the blackout period at superior conjunction. After superior conjunction, coverage reverts to two 34 m antennae at each site until the end of the nominal mapping mission.

Figures 32 and 33 show that the telemetry link margin provided by two 34 meter antennae is sufficient both during the mission period (except during superior conjunction) and throughout the 24-hour period.

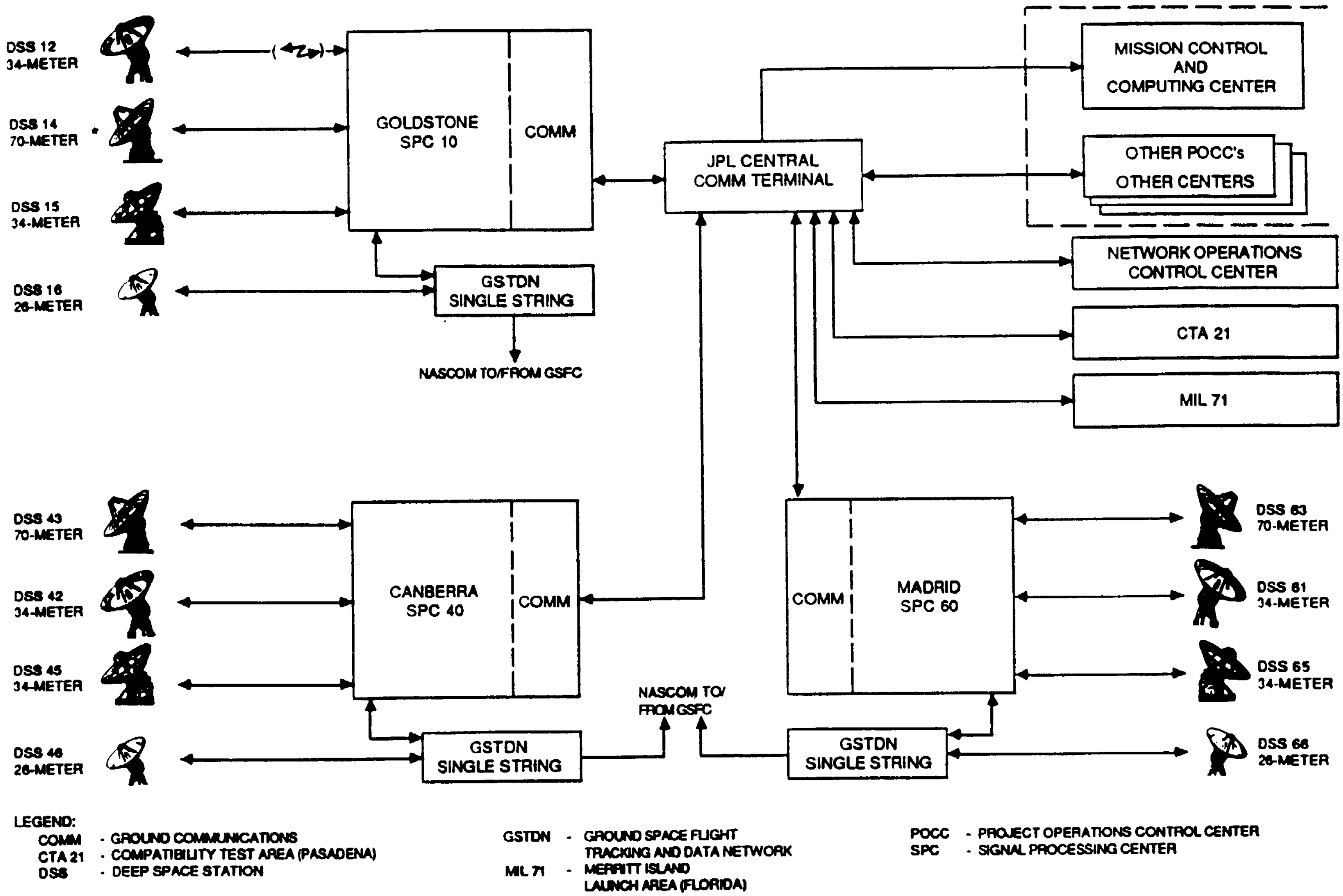

Figure 30. DSN Configuration

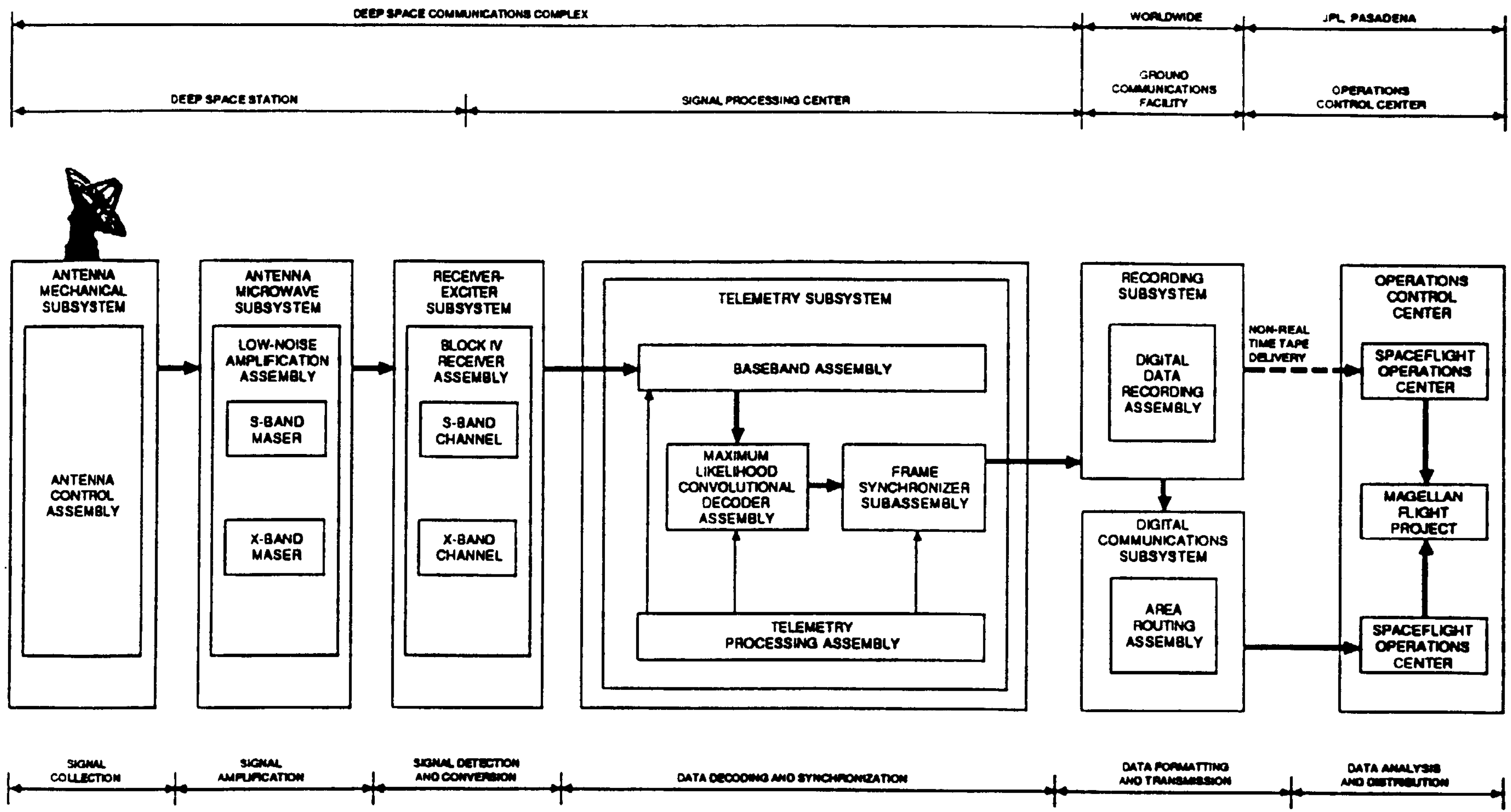

Figure 31. Network Telemetry Data Flow Path

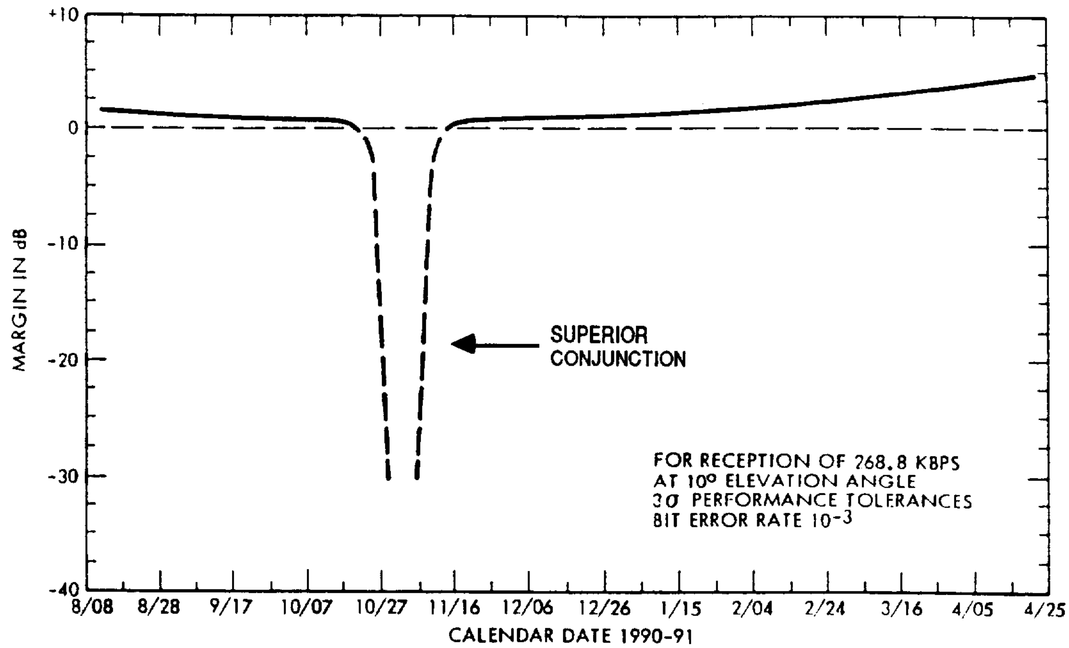

Figure 32. Telemetry Link Margin with Two 34-Meter Antennae

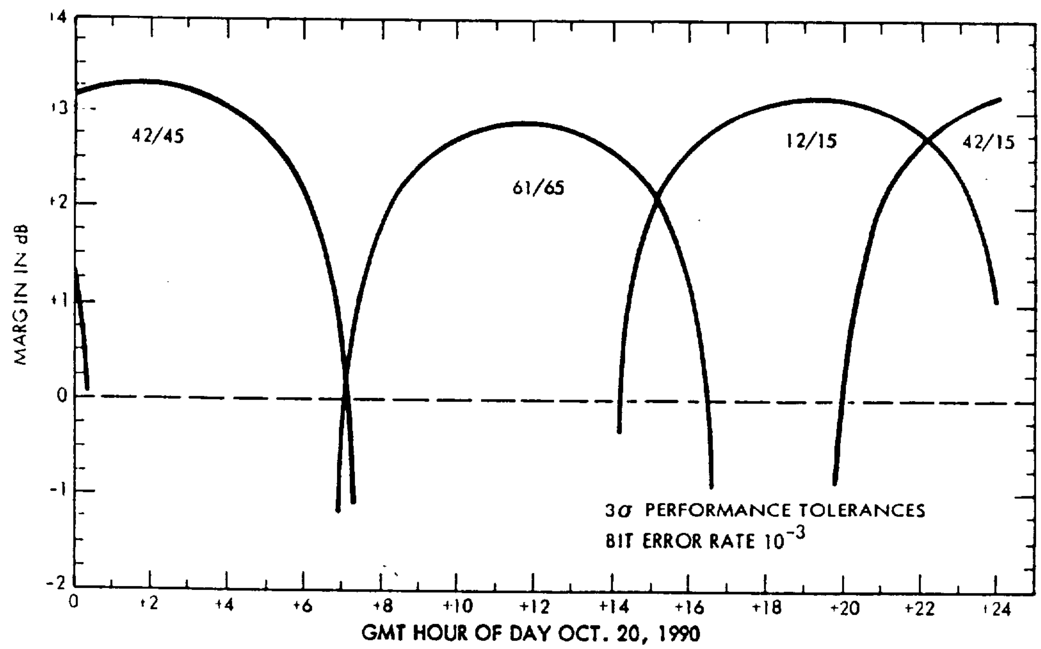

Figure 33. Telemetry Link Margin with Two 34-Meter Antennae (24-Hour)

From Venus orbit insertion to superior conjunction, the distance to Venus increases continually. After superior conjunction the distance decreases until the end of the nominal mission. Shortly before superior conjunction, the solar effects on communication become increasingly serious, ultimately resulting in complete loss of communication for several days. Figure 34 shows the Sun-Earth-Probe (SEP) angle during the superior conjunction period. The DSN cannot reliably provide sufficient bit error rate for SEP angles less than 7° for S-band communication or 2.5° for X-band. The SEP angle remains below 2.5° from October 24 to November 11, 1990.

Figure 35 shows periods during which 70 m coverage is available from Goldstone, Canberra, and Madrid. The rise and set times assume a minimum usable elevation angle of 10°. Shaded regions show station overlap. Overlap periods are used by the Navigation Team to gather and process VLBI precision tracking data. The periods of coverage/overlap vary throughout the mission due to changes in Venus's declination.

During the Magellan mission lifetime, DSN must support multiple spacecraft. Figure 36 charts the right ascension of all spacecraft which will require support, and indicates that the problem of potential DSN conflicts is manageable.

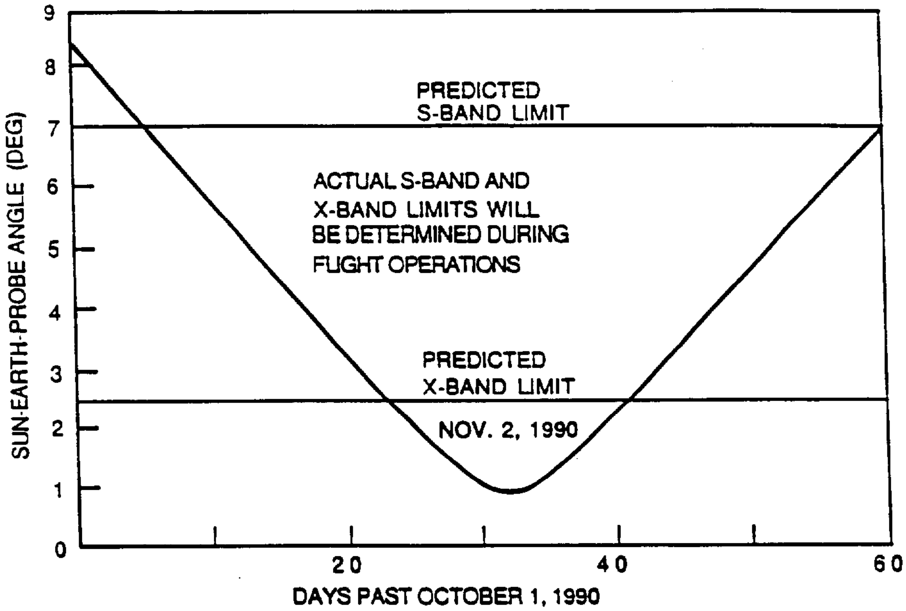

Figure 34. Sun-Earth-Probe (SEP) Angle vs. Time Near Superior Conjunction

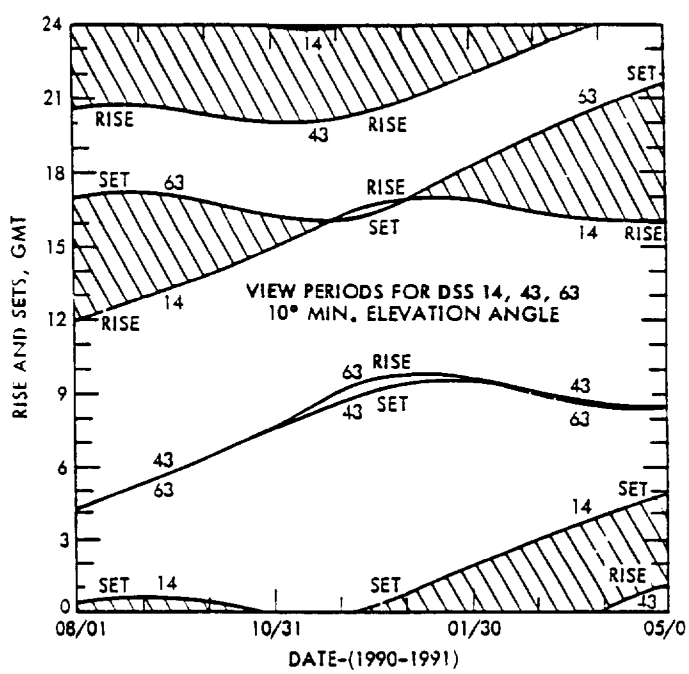

Figure 35. Venus Rise and Set Throughout Nominal Mapping Mission

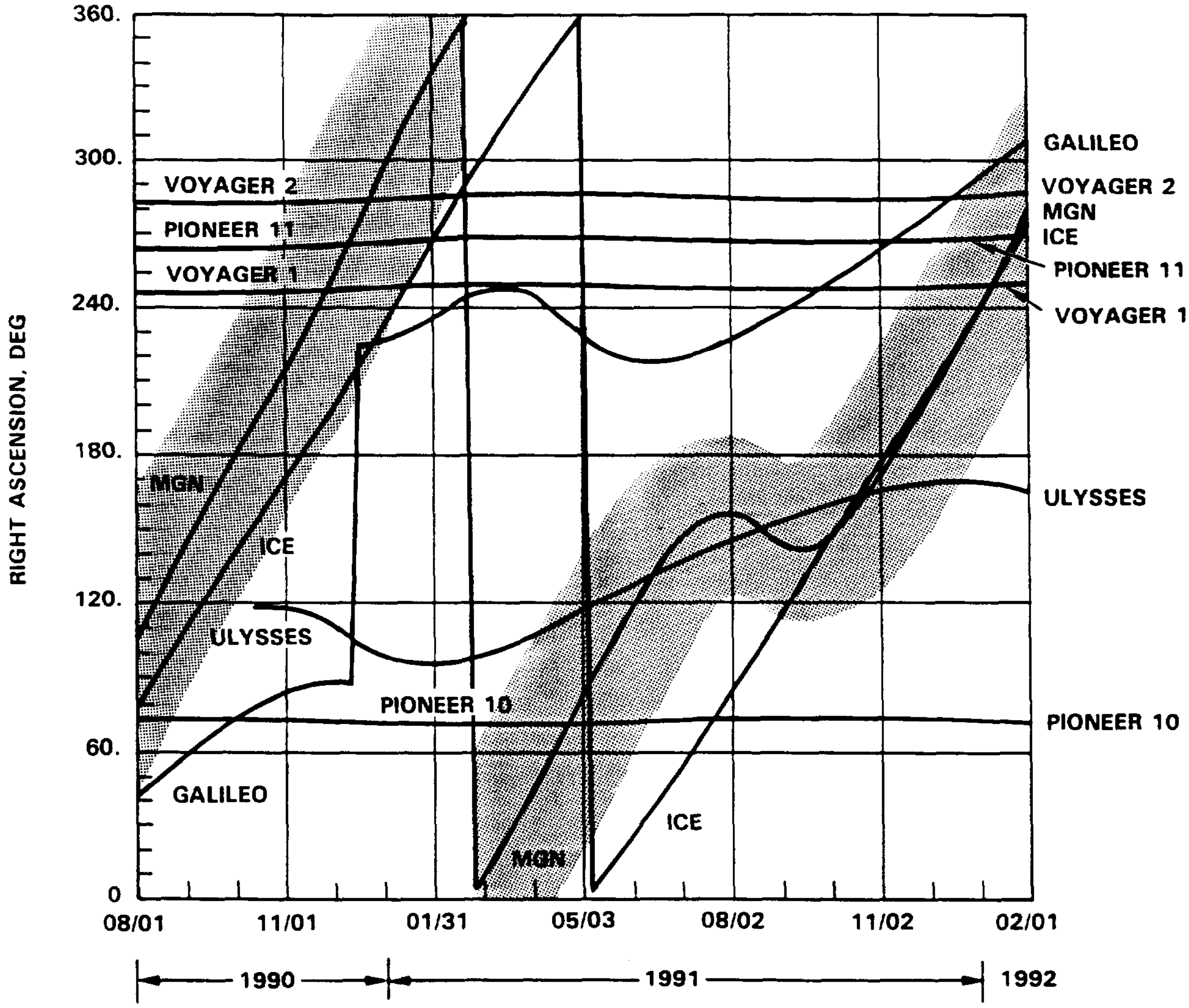

Figure 36. Spacecraft Right Ascension vs. Date

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NASA Office of Space Science and Applications

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Samuel W. Keller	Deputy Associate Administrator for Space Science and Applications
Dr. Geoffrey A. Briggs	Director of Solar System Exploration Division
Frank A. Carr	Chief, Flight Programs Branch
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Joseph M. Boyce	Magellan Program Scientist

NASA Office of Space Flight

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Charles R. Gunn	Director, Unmanned Launch Vehicles and Upper Stages
Paul E. Goozh	Chief, Solid Stages
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NASA Office of Space Operations

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Allan G. Conrad	Magellan Mission Operations Manager
David F. Quinn	Magellan Financial Manager

Kennedy Space Center

Forrest S. McCartney	Director
Robert B. Sieck	Director, Shuttle Management and Operations
John T. Conway	Director, STS Cargo Operations

Johnson Space Center

Aaron Cohen	Director
Richard H. Kohrs	Deputy Director, National Space Transportation System Program Office
Eugene F. Kranz	Director, Mission Operations

STS-30/Atlantis Flight Crew

David M. Walker	Commander
Ronald J. Grabe	Pilot
Dr. Norman E. Thagard (M.D.)	Mission Specialist
Dr. Mary L. Cleave	Mission Specialist
Mark C. Lee	Mission Specialist

Marshall Space Flight Center

J. R. Thompson	Director
Sidney P. Saucier	Manager, Special Projects Office
Parker V. Counts	Manager, Inertial Upper Stage Project

USAF - Space Division

Col. V. W. Whitehead	Deputy Commander, Launch Systems, SD/CL
Col. Dennis E. Beebe	Director, IUS Program
Col. James L. Hane	Commander, Consolidated Space Test Center
Col. Robert B. Bourne	Cdr. Aerospace Test Group 6555th ASTG/CC (at KSC)

PROGRAM COSTS

The funding for the Magellan project is described in the following table. The funding data are in millions of real year dollars, and include costs for JPL, NASA Centers, contractors, and NASA Headquarters.

MAGELLAN PROGRAM COSTS (Dollars in Millions)									
	Prior Years	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*TOTAL*
Development	420.1	43.1							463.2
Mission Operations		17.1	37.8	31.9					86.8
Science Data Analysis				.8	5.1	5.4	5.7	6.1	23.1
Project Total	420.1	60.2	37.8	32.7	5.1	5.4	5.7	6.1	573.1

APPENDIX

History Of Venus Exploration

Exploration of Earth's nearest planetary neighbors has been a goal of NASA scientists from the agency's earliest days. Missions to Venus and Mars would require more sophisticated spacecraft than the satellites sent into orbit around Earth or the sun to observe the phenomena of interplanetary space. Spacecraft directed toward other planets would need complex communications, data storage, and guidance and control equipment, computers, and scientific instruments with which to sound distant atmospheres. The weight of this new hardware would require a launch vehicle more powerful than those available to NASA in the early 1960s. From the first preliminary studies, space agency planners built their designs for planetary explorers around the Centaur upper stage. Centaur's availability (or its lack) determined the direction of the first 10 years of planetary mission planning.

From 1960 through 1968, ten distinct Mariner projects were approved, but troubles with Centaur and the budget caused the cancellation of four. Proposals for Mariner-Venus 1962 (also called Mariner R) led to the launches of the Venus flyby missions *Mariner 1* and *2*. Only *Mariner 2* reached its target, returning 42 minutes of data about the atmosphere and surface of the planet. *Mariner 3* and *4* conducted a similar flyby mission to Mars. The only other Mariner launched during NASA's first decade was *Mariner 5*, which took advantage of the 1967 Venus launch period. The spacecraft flew by Venus on October 19, 1967, and measured its atmosphere, mass, and interactions with the solar wind.

The first five Mariners weighed 200-260 kilograms and were launched by Atlas-Agena B or D. They carried scientific instruments designed by various NASA centers and universities. Solar panels provided spacecraft power, and the Deep Space Network at the Jet Propulsion Laboratory (JPL) was responsible for tracking and communications.

The Pioneer Venus missions, launched in 1978, were designed to undertake a detailed investigation of planet Venus. The Pioneer 13 multiprobe spacecraft used heat-resistant probes to radio back to Earth in-situ measurements from the upper atmosphere, through the dense clouds, and down to the surface of Venus, despite its 470 °C temperature. The Pioneer 12 Orbiter, which is still in orbit around Venus, has mapped the planet's surface by radar, imaged its cloud systems, explored its magnetic environment, and observed its interactions with the solar wind.

The four Pioneer probes entered the Venusian atmosphere at widely separated locations in day and night hemispheres. They measured temperature, pressure, and density down to the planet's surface. They discovered diurnal changes in the upper atmosphere and found that Venus' atmosphere is cooler at high altitudes and much hotter at low altitudes than Earth's. The temperature below the clouds was found to be relatively constant planet-wide at a given height. Instead of turbulence, unexpectedly stable atmospheric layers were found below the clouds.

The probes charted vertical winds and determined the chemical composition of the atmosphere which, unlike Earth, is mainly carbon dioxide and nitrogen with very little oxygen or water vapor. The concentrations and isotopic ratios of rarer atmospheric gases were also measured. Unexpectedly, there were high abundances of neon and of argon-36 and -38 isotopes, which suggested that Venus and Earth received different original volatile components from the solar nebula out of which the planets formed.

The ratio of deuterium to hydrogen on Venus appears to be 100 times that on Earth, which suggests that there has been a preferential escape of a large amount of hydrogen from Venus. (Since the lighter hydrogen isotope would escape more readily, the deuterium ration would increase.) This suggests that Venus probably had a large quantity of water, perhaps as much as an ocean, sometime during its history. The ocean may have been lost because a "greenhouse" effect trapped solar heat in Venus' atmosphere, making the planet too hot to retain water on its surface.

Pioneer Venus Orbiter radar provided altimetry maps for much of the surface of Venus, resolving features as small as about 80.5 km across. On these maps, scientists identified volcanoes that might still be active; continental areas with great plains and mountain ranges (in which one peak rises 10,800 m); island masses rising from global plains; rift valleys such as Diana Chasma, which is 2,900 m deep; some craters; and extensive areas of global plains with relatively flat and monotonous surfaces. Venus is closer to being a sphere than are Earth and other planets, as might be expected from its slow rotation, which is 242 times slower than Earth's.

The U.S.'s Pioneer Venus radar altimetry data were used to select targets for subsequent USSR Venus probes. Important international cooperation has been enhanced by exchanges of information about Venus between the two countries. Tables 7 and 8 show the US and USSR Venus space flights to date.

Precise measurements of spacecraft orbits around Venus show that mountainous formations are less dense than the global crust, and that, as on Earth, they appear to be supported on a liquid interior. Orbital observations of atmospheric movement charted movements of masses of the atmosphere, with global winds reaching 354 km/h at the cloud tops. These winds generally blow westward, with little north or south motion. Electrical signals from Venus detected by Pioneer may be caused by lightning flashes in gas clouds arising from active volcanoes. They do not appear to have any other terrestrial counterpart.

The Pioneer Venus Orbiter travels in an elliptical orbit around the planet. This enables its instruments to sample various regions of the planet's ionosphere (i.e., the region of charged particles in the upper atmosphere), which is thinner than the ionosphere of Earth. Venus has no intrinsic magnetic field to shield it from the solar wind, but the wind itself induces a weak magnetic field.

The induced magnetic field deflects the solar wind and gives rise to a bow shock and an ionopause (which has no terrestrial counterpart). The ionopause is the boundary between the ionosphere and the solar wind. The spacecraft showed that the ionopause exists on the night as well as on the day side of the planet, and it identified and mapped specific ionospheric regions: an ionosheath, a mantle, and a wake. Changes in the ionosphere and the environment surrounding Venus are attributable to solar activity and the strength of the solar cycle. A new understanding of how a planet without a magnetic field interacts with the solar wind is being developed, and explanations for some of the differences between Earth and Venus are evolving.

The most significant advance in knowledge of the Venus surface was provided by the Soviet Venera 15 and 16 missions over the period from 1983 to 1987. Two identical spacecraft mapped the northern hemisphere between October 1983 and July 1984. The images have a resolution of 2 to 4 km and were obtained with a synthetic aperture radar system operating at 8 cm wavelength. The region from 30° N latitude to the north pole was mapped, covering 25 percent of the planet. Mapping was conducted from north to south from an elliptical orbit, with the radar looking to the right at 10° from the local vertical. The orbital period was 24 hours, with an inclination of 92.5° and periapsis of 62° N. An altimeter obtained simultaneous observations with a range precision of 50 m over a 40 to 50 km diameter spot. All observations were made from orbital altitudes between 1000 and 2000 km.

Veneras 15 and 16 also carried Fourier spectrometers for infrared observations of the atmosphere. Spectra were obtained in the 280-1500 cm^{-1} range with a resolution of 5 cm^{-1} and spatial resolution of about 100 km at the cloud tops. Bands have been identified for CO_2, H_2O, H_2SO_4, and SO_2.

The Soviet VEGA 1 and 2 missions provided surface and atmosphere data for regions and altitudes previously unexplored. The VEGAs deployed landers and balloons at Venus before going on to encounter Halley's comet. VEGA 1 landed at 7.2° N, 177.8° E on June 11, 1985, and returned data for 20 minutes. VEGA 2 landed 1000 km to the southeast at 6.45° S and 181.08° E on June 15, 1985. Thirty-six minutes of data were returned, including information about a surface sample.

The VEGA balloons provided very exciting Venus atmospheric studies. Each of the two Soviet VEGA spacecraft carried a 3 m diameter helium balloon with an instrumented gondola. They measured pressure, temperature, vertical wind velocity, ambient light, lightning occurrences, and backscatter from cloud particles. The balloons travelled more than 100° around 54 kilometers.

The two VEGA balloon experiments were launched on similar trajectories a few degrees above and below the equator. The balloons were carried around Venus by the zonal winds and were tracked by an international array of 20 radio observatories. The tracking data show that each balloon was carried westward about 11,500 km at an average speed of 70 meters per second. The balloons recorded vertical winds of 1 to 2 meters per second with peak vertical velocities of 3 meters per second. Although somewhat higher than predicted, these velocities are consistent with thermal convection. The 6.5 °C temperature differences, consistently observed between the two balloons, was larger than predicted and was interpreted as large-scale non-axisymmetry disturbances that propagate westward with respect to the surface. Surface topography appears to have an effect on the atmospheric motions seen by the VEGA 2 balloon. The observed thermal structure may indicate that the middle cloud layer is more or less adiabatic. The observed temperature differences suggest the presence of discrete air masses.

The Venera and VEGA landers provided direct in-situ measurements which are very useful for interpretation of remote sensing measurements. The altimeter and SAR remote sensing instruments showed areas of high radar brightness (high backscatter) consistent with the radar characteristics of solidified flows of basaltic lavas on Earth. These lava flows appear bright in radar images because of their rough, highly radar-scattering surfaces. The landers conducted sample analyses which confirmed that the surface material is chemically close to terrestrial basalts or their deeper-lying counterparts, the gabbros. Venera 14 and VEGA 2 landed on material containing little potassium. Veneras 8 and 13 landed on highly alkaline rocks that do not match the compositional trends found among terrestrial rocks.

Physically, the small-scale surfaces near the landers differed considerably. Panoramic camera images of the Venera lander sites show the local sites. Venera 13 showed a fine-grained "soil" of small particles between widely separated rocky outcrops. Venera 14 landed on a volcanic plain on which thin sheets of low-cohesion rocks have accumulated in layers and the fine-grained "soil" is absent. These local physical surface types correspond to the low-lying basins of low radar reflectivity and the higher upland regions. The fine-grained "soil" is apparently eroded debris or volcanic ash accumulated in depressions.

Although the landers have given tantalizing data on several local sites, their correct interpretation is unclear because of the enormous gap between the very large-scale data from the remote sensor measurements and the centimeter-scale features seen in the lander panoramas. The significantly improved radar maps produced by Magellan may allow a consistent interpretation of the data collected at these two scales.

Table 7. USA Venus Space Flights

USA VENUS SPACE FLIGHTS

Spacecraft	Mission	Launch Date	Arrival Date	Remarks
Mariner 1	Venus Flyby	Jul 22, 1962		Destroyed shortly after launch when vehicle veered off course.
Mariner 2	Venus Flyby	Aug 27, 1962	Dec 14, 1962	First successful planetary flyby. Provided instrument scanning data. Entered solar orbit.
Mariner 5	Venus Flyby	Jun 14, 1964	Oct 19, 1967	Advanced instruments returned data on Venus's surface temperature, atmosphere, and magnetic field environment. Entered solar orbit.
Mariner 10	Venus/Mercury Flyby	Nov 3, 1973	Feb 5, 1974 (Venus)	First dual-planet mission. Used gravity of Venus to attain Mercury encounter. Provided first ultraviolet photographs of Venus; returned close-up photographs and detailed data of Mercury. Transmitter was turned off on March 24, 1975, when attitude control gas was depleted. Craft inoperable in solar orbit.
Pioneer Venus 1	Venus Orbiter	May 20, 1978	Dec 4, 1978	Mapped Venus' surface by radar, imaged its cloud system, explored its magnetic environment and observed interactions of the solar wind with a planet that has no intrinsic magnetic field. Provided radar altimetry maps for nearly all of the surface of Venus, resolving features down to about 50 miles across. Still operating in orbit around Venus.
Pioneer Venus 2	Venus Probe	Aug 8, 1978	Dec 9, 1978	Dispatched heat-resisting probes to penetrate the atmosphere at widely separated locations and measured temperature, pressure, and density down to the planet's surface. Probes impacted on the surface.

Table 8. USSR Venus Space Flights

USSR VENUS SPACE FLIGHTS

Spacecraft	Mission	Launch Date	Arrival Date	Remarks
Venera 1	Venus Probe	Feb 12, 1961		First Soviet Planetary flight; launched from Sputnik 8. Radio contact lost during flight; not operating when it passed Venus.
Sputnik 19	Venus Probe	Aug 25, 1962		Unsuccessful Venus attempt.
Sputnik 20	Venus Probe	Sep 1, 1962		Unsuccessful Venus attempt.
Sputnik 21	Venus Probe	Sep 12, 1962		Unsuccessful Venus attempt.
Zond 1	Venus Probe	Apr 2, 1964		Communications lost; spacecraft went into solar orbit.
Venera 2	Venus Probe	Nov 12, 1965	Feb 27, 1966	Passed by Venus, but failed to return data.
Venera 3	Venus Probe	Nov 16, 1965	Mar 1, 1966	Impacted on Venus, becoming the first spacecraft to reach another planet. Failed to return data.
Venera 4	Venus Probe	Jun 12, 1967	Oct 18, 1967	Descent capsule transmitted data during parachute descent. Sent measurements of pressure, density, and chemical composition of the atmosphere before transmissions ceased.
Venera 5	Venus Probe	Jan 5, 1969	Mar 16, 1969	Entry velocity was reduced by atmospheric braking before deployment of main parachute. Capsule entered the atmosphere on the planet's dark side; transmitted data for 53 minutes while traveling into the atmosphere before being crushed.

Table 8. USSR Venus Space Flights (continued)

USSR VENUS SPACE FLIGHTS

Spacecraft	Mission	Launch Date	Arrival Date	Remarks
Venera 6	Venus Probe	Jan 10, 1969	Mar 17, 1969	Descent capsule entered the atmosphere on the planet's dark side; transmitted data for 51 minutes while traveling into the atmosphere before being crushed.
Venera 7	Venus Lander	Aug 17, 1979	Dec 15, 1970	Entry velocity was reduced aerodynamically before parachute deployed. After fast descent through upper layers, the parachute canopy opened fully, slowing descent to allow fuller study of lower layers. Gradually increasing temperatures were transmitted. Returned data for 23 minutes after landing.
Cosmos 359	Venus Lander	Aug 22, 1970	Unsuccessful Venus attempt; failed to achieve escape velocity.	
Venera 8	Venus Lander	Mar 27, 1972	July 22, 1972	As the spacecraft entered the upper atmosphere, the descent module separated while the service module burned up in the atmosphere. Entry speed was reduced by aerodynamic braking before parachute deployment. During descent, a refrigeration system was used to offset high temperatures. Returned data on temperature, pressure, light levels and descent rates. Transmitted from surface for about 1 hour.
Cosmos 482	Venus Lander	Mar 31, 1972	Unsuccessful Venus probe; escape stage misfired leaving craft in Earth orbit.	

Table 8. USSR Venus Space Flights (continued)

USSR VENUS SPACE FLIGHTS

Spacecraft	Mission	Launch Date	Arrival Date	Remarks
Venera 9	Venus Orbiter and Lander	Jun 8, 1975	Oct 22, 1975	First spacecraft to transmit a picture from the surface of another planet. The lander's signals were transmitted to Earth via the orbiter. Utilized a new parachute system, consisting of six chutes. Signals continued from the surface for nearly 2 hours 53 minutes.
Venera 10	Venus Orbiter and Lander	Jun 14, 1975	Oct 25, 1975	During descent, atmospheric measurements and details of physical and chemical contents were transmitted via orbiter. Transmitted pictures from the surface.
Venera 11	Venus Orbiter and Lander	Sep 9, 1978	Dec 25, 1978	Arrived at Venus 4 days after Venera 12. The two landers took nine samples of the atmosphere at varying heights and confirmed the basic components. Imaging system failed; did not return photos. Operated for 95 minutes.
Venera 12	Venus Orbiter and Lander	Sep 14, 1978	Dec 21, 1978	A transit module was positioned to relay the Lander's data from behind the planet. Returned data on atmospheric pressure and components. Did not return photos; imaging system failed. Operated for 110 minutes.
Venera 13	Venus Orbiter and Lander	Oct 31, 1981	Mar 1, 1982	Provided first soil analysis from Venusian surface. Transmitted eight color pictures via orbiter. Measured atmospheric chemical and isotopic composition, electric discharges, and cloud structure. Operated for 127 minutes.

Table 8. USSR Venus Space Flights (continued)

USSR VENUS SPACE FLIGHTS

Spacecraft	Mission	Launch Date	Arrival Date	Remarks
Venera 14	Venus Orbiter and Lander	Nov 4, 1981	Mar 3, 1982	Transmitted details of the atmosphere and clouds during descent; soil sample taken. Operated for 57 minutes.
Venera 15	Venus Orbiter	Jun 2, 1983	Oct 10, 1983	Obtained first high-resolution pictures of polar area. Compiled thermal map of almost entire northern hemisphere.
Venera 16	Venus Orbiter	Jun 7, 1983	Oct 16, 1983	Provided computer mosaic images of a strip of the northern continent. Soviet and U.S. geologists cooperated in studying and interpreting these images.
Vega 1&2	Venus/Halley	Dec 15, 1984	Jun 11, 1985 (Venus) Mar 6, 1985 (Halley) Jun 15, 1985 (Venus) Mar 9, 1985 (Halley)	International two-spacecraft project using Venusian gravity to send them on to Halley's Comet after dropping the Venusian probes. The Venus landers studied the atmosphere and acquired a surface soil sample for analysis. Each lander released a helium-filled instrumented balloon to measure cloud properties. The other half of the Vega payloads, carrying cameras and instruments, continued on to encounter Comet Halley.

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