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REQUIREMENTS AND CAPABILITIES FOR PLANETARY MISSIONS:
Mars Polar Orbiter/Penetrator 1981

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Foreword

This volume represents one of a series of requirements and capabilities for planetary missions assembled from recent study activities at JPL. The purpose of this series of documents is to provide a summary of these studies which may be readily used in subsequent efforts. Emphasis is upon requirements and associated capabilities of the spacecraft and mission design as developed in the study. No particular priority of individual missions should be assumed from the sequence of these reports.

The other published volume in this series is SP 43-27, Vol. 1, *Mariner Encke Ballistic Flyby 1980,* November 1975. These volumes were prepared by the Mission Engineering Section of the Project Engineering Division.

Mars Polar Orbiter/Penetrator

Launch Date:	October 1981
Orbit Insertion:	August 1982
Orbital Lifetime:	2 years
Injected Mass:	3357 kg
Final Orbited Mass:	1092 kg
Orbiter Instrument Mass:	97 kg
Number of Penetrators:	6
Mass of Penetrator System:	413 kg
Launch Vehicle*	Titan III-E/Centaur, one launch

Objectives:

Orbiter

To survey the geochemistry of Mars. To map surface elevation and roughness. To make detailed geological studies. To perform climatological investigations, including determination of polar glacier composition and duststorm mechanisms. To determine the gravitational field of the planet. To make reconnaissance of sites for future landings.

Penetrators

To establish the seismic network and determine the internal structure of Mars. To make subsurface measurements of the abundance of important rock-forming elements. To measure the abundance of chemically and physically bound water in the Martian soil. To measure the density profile of the upper few meters of the Martian soil.

Typical Science Investigations:

Orbiter

Gamma-ray spectrometer

Radar altimeter

High-resolution imaging system

Synoptic imaging system

IR multichannel radiometer

IR-visible reflectance spectrometer

UV photometer

Radio science

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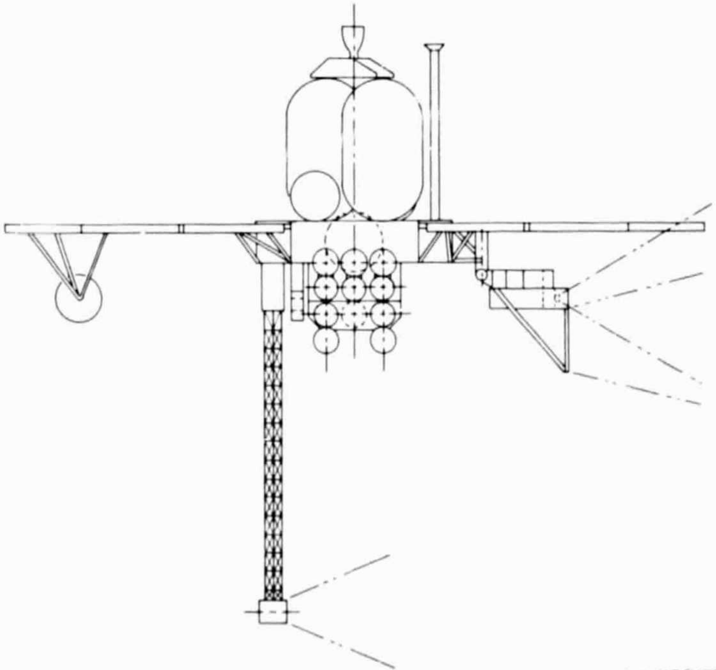
* This study was performed using the Titan IIIE/Centaur launch vehicle as reference. The Shuttle/IUS will be used in follow-on studies.



Penetrators

Three-axis seismometer

Alpha-scattering spectrometer

P_2O_5 hygrometer

Acceleration sensor

Mission Description:

A single spacecraft modified from the Viking Orbiter design carries a new remote-sensing payload and six penetrators. This spacecraft is injected into an elliptical, Mars-synchronous, polar orbit after a Type II transfer from Earth. The penetrators are released at intervals over a 60- to 80-day period and interrogated daily throughout the mission. After the release of the probes, the spacecraft orbit is trimmed into a 2.46-h, 1000-km circular orbit that is Sun-synchronous. The probe deployment and the later remote sensing phase of the mission are largely independent and are programmed in a simplified standard mode to minimize cost. X-band telemetry is used to increase data return. A 2-year obital mission is planned.

I. Science

A. Rationale

The exploration of Mars aims at discovering the manner in which the planet has evolved, to which end the following information is sought:

(1) The chemical composition of the planet.

(2) The internal density distribution.

(3) The average rate of loss of internal heat.

(4) The nature and chronology of surface processes.

(5) The inventory of volatiles and the dynamic relationship between the various sources and sinks.

(6) The composition of the atmosphere and the nature of atmospheric loss processes.

Previous missions have provided valuable information concerning items (4) and (6), but present thinking on the other items stems primarily from theoretical studies. The combined orbiter/penetrator mission can shed light on all of the items in the above list, with the probable exception of the rate of loss of internal heat.

B. Objectives

The objectives of this combined mission are:

(1) Geochemistry mapping, including determination of the phase composition and abundance of surface materials.

(2) Internal density distribution, which includes seismic analyses for inferring the radial density and phase distribution of Mars.

(3) Nature and chronology of surface processes by means of correlated imaging, compositional mapping, radar altimetry, surface roughness, and gravitational field measurements.

(4) Inventory of volatiles and source–sink relationships, which includes climatology investigations and other studies relating the surface/atmosphere interactions.

C. Typical Payload

1. Orbiter. A typical payload for the mission is based upon instruments that have been flown on previous missions:

(1) *Gamma-ray spectrometer.* The spectrometer measures the flux of gamma-rays from natural radioactive isotopes and also from those produced by the interaction of surface matter with incident cosmic rays. It can be used to determine the presence of important elements and volatiles in the surface materials.

(2) *Radar altimeter.* A simple radar altimeter would provide 15-m range accuracy with a 700-m spot size and could be used to map the entire planet to these vertical and horizontal accuracies. Measurements of the strength of the reflected signal would be used to infer average surface roughness and dielectric constant.

(3) *High-resolution imaging system.* This system would be similar to the dual-vidicon camera used by the Viking Orbiter. An alternative system is a 1000-element charge-coupled device (CCD) with a 2-m focal length, which would be able to provide 20-m resolution.

(4) *Synoptic imaging system.* The wide-angle camera would acquire data for 600 km on either side of the ground track, thereby providing complete planetary coverage each day poleward of 50-deg latitude. These data would be used to study the growth of dust storms, the weather systems within the polar hoods, the growth and retreat of the polar caps, surface albedo variations, and the seasonal variation of tropical water ice clouds.

(5) *IR multichannel radiometer.* The IR sounder provides atmospheric temperature–pressure profiles and would operate in conjunction with the synoptic imaging experiment to characterize the meteorology and dynamics of the planet.

(6) *IR-visible reflectance spectrometer.* The reflectance spectrometer would provide a high-resolution (1–10 km) mineralogical map of Mars and would monitor atmospheric water content and surface condensation of water and carbon dioxide.

(7) *UV photometer.* This instrument would be used to measure seasonal variations in the distribution of atomic hydrogen (H) and ozone (O_3) in the lower atmosphere of Mars.

(8) *Radio science.* Radio occultations occurring within the last half of the mission would provide data on seasonal pressure changes and on the figure of the planet. X-band and S-band tracking of the spacecraft would allow the gravity field of the planet to be determined with a 1000-km-diameter resolution element.

2. Penetrators. A typical payload for the Mars penetrators could consist of the following instruments:

(1) *Three-axis seismometer.* An array of seismometers on Mars, well coupled to the surface, could determine the internal seismicity of the planet and, by measuring P- and S-wave propagation, could determine the internal seismic velocity distribution, thereby providing information about the composition and physical properties of the Martian interior. In addition, the array could determine the meteorite flux on Mars.

(2) *Alpha-scattering spectrometer.* The alpha-proton instrument would be used to obtain a more complete chemical analysis of Martian material than Viking can provide. Quantitative information on the important light elements (C, O, N, F, Na) would be acquired from which the state of hydration, fraction of carbonates, and presence of permafrost could be deduced.

(3) *P_2O_5 hygrometer.* The hygrometer, which would operate in conjunction with a heater to volatilize part of the regolith water, would be capable of a semi-quantitative analysis of the regolith for water and ice.

(4) *Acceleration sensor.* Data from this sensor would assist in the determination of the stratification of surface material through which the penetrator had traveled.

II. Mission Description

The spacecraft is launched on a Titan IIIE/Centaur booster in October 1981, with orbit insertion at Mars occurring in August 1982. The general calendar of events, including Mars seasonal characteristics, is shown in Fig. 1.

After insertion, the orbit is trimmed to achieve the following characteristics for the desired Mars synchronous orbit:

Period:	24.6 h
Inclination:	96 deg
Periapsis altitude:	1010 km
Apoapsis altitude:	33,100 km
Eccentricity:	0.78

Taking into account the apsidal precession rate of about 0.1 deg per day and assuming that the probes are deployed over a 60-day period with atmospheric entry angles of between -22-1/2 and -12-1/2 deg, the following landing zones are accessible:

Northern Periapsis	Southern Periapsis
54°N - 84°N	46°S - 76°S

Longitudinal separation of the penetrators is achieved by choosing the exact orbit period to be slightly different from the Martian rotation period, such that the ground trace moves 1 to 2 deg in longitude every day. Since the ability to target the penetrators in the cross track direction is limited, each probe is released on the day on which the ground track longitude is over the target. Thus releases (recoilless firing from tubes that would also act as bioshields) take place at irregular intervals determined by the landing sites selected. An average period between penetrator launches might be 10 days, but in principle, the probes can be deployed on successive revolutions if desired. The deceleration profiles and the chemistry data are returned within a few days, and the probe then becomes a seismic (and perhaps meteorological) station, accumulating and returning data every day if possible. Depending upon the distribution of the chosen landing sites, contact with some of the earlier landing probes may be lost temporarily while the last probes are being deployed.

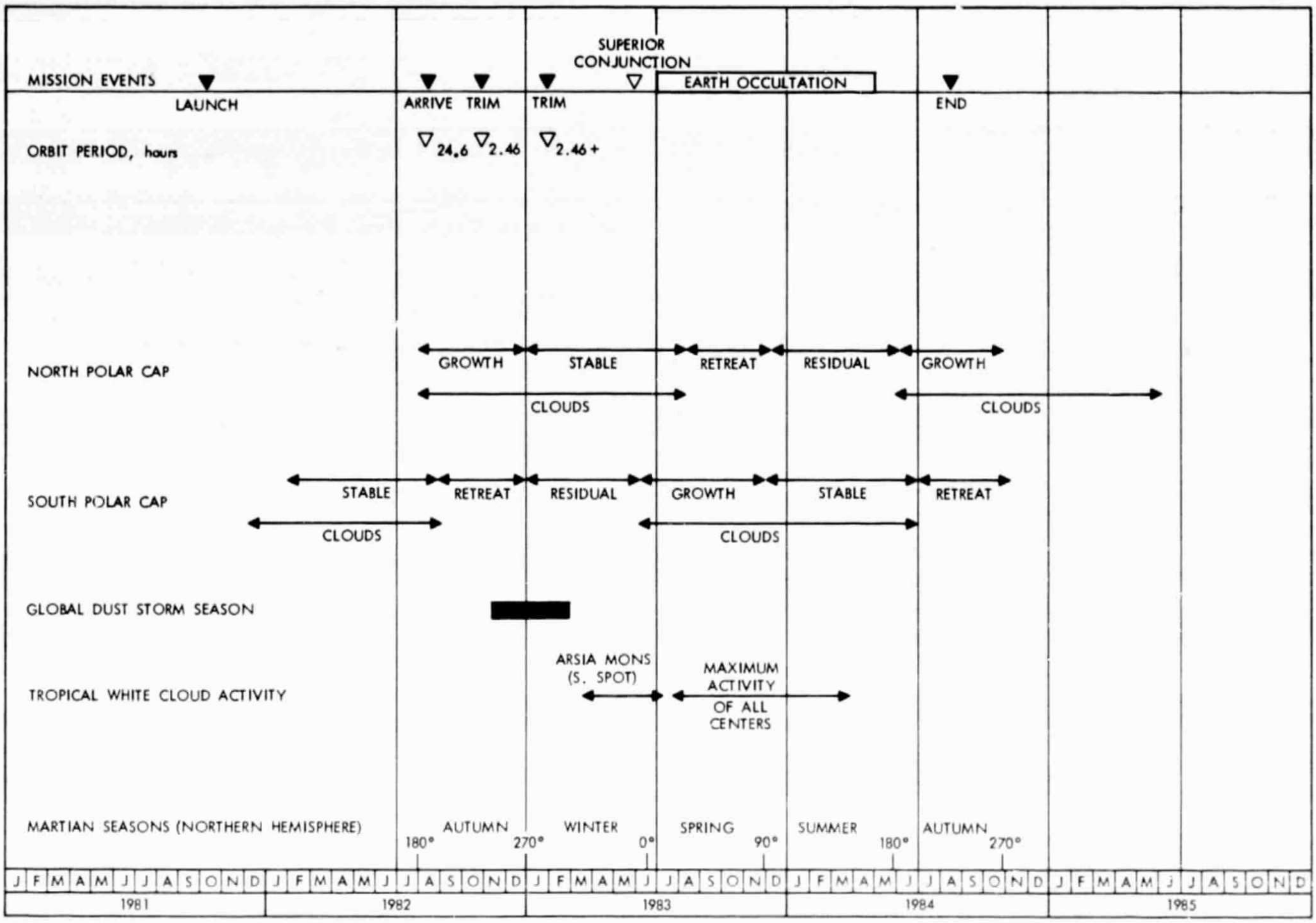


Fig. 1. General calendar of events

After all the probes are deployed, the spacecraft's orbit can be circularized as needed for the remote sensing experiments. When the spacecraft first arrives at Mars, the orbit is aligned roughly along the terminator, and, as the mission proceeds, this orientation changes by about 0.5 deg per day until, after 60 days, the orbit is aligned at about 30 deg from the terminator. It is in the following 20 days that circularization of the orbit must occur, since the circular orbit is Sun-synchronous, and undesirable solar occulations would occur if the orientation with respect to the terminator were allowed to exceed about 40 deg. The circular Sun-synchronous orbit has the following parameters:

Period:	2.46 h
Inclination:	96 deg
Altitude:	1010 km
Eccentricity:	0

The orbit period is trimmed to be exactly one tenth of the Mars day, so that the spacecraft overflies the same ten sectors of the planet each day. The consequent limitation in the total accessible coverage is intended to allow the gamma-ray spectrometer to accumulate observation time in order to make useful elemental abundance measurements over 500-km-diameter regions in a reasonable amount of time. It is estimated that about 100 days of data accumulation will be needed to make such measurements over the available 25% of the planet. Following the achievement of this goal, the orbit period is trimmed to allow the ground track to move east or west at a slow, steady rate, such that the whole planet is overflown about every 50 days, thereby allowing observations to be made over any part of the planet. This mode of observation is continued until the end of the mission.

A simple science operation is visualized, with minimum adaptivity—important factors in reducing the cost of the mission and the need for major scientist participation in mission operations. Simplicity is achieved by ensuring the return of a large amount of data with essentially complete planetary coverage each day by the IR sounder and wide-angle cameras. Thus nearly all dynamical phenomena are observed automatically. Decisions, which can be planned with ample lead-time, will have to be made as to where the high-resolution imaging and radar sounding will be acquired and which of these will be recorded on any particular revolution.

All of the data except for the high-resolution imaging and the radar sounding are sent back directly in real time at ~30 kbps using X-band telemetry. The recorded data are sent back at ~120 kbps to the Goldstone antenna only—a cost-saving measure to avoid the rental of high-speed data lines.

III. General Spacecraft Characteristics

A. Basic Assumptions

The spacecraft proposed for the 1981 mission is based on the Viking 1975 Orbiter, modified appropriately to accept a new science payload and to accommodate the penetrators and their launch system. The principal modifications to the spacecraft are as follows:

(1) Addition of penetrator package.

(2) Stretch of propulsion tanks by about 25 cm to accommodate orbital changes.

(3) Extra attitude control gas (45 kg) in tanks external to the bus, replacing the internal tanks.

(4) X-band radio system to permit high-rate data playback.

(5) Rotatable boom for gamma-ray spectrometer.

(6) Twin CCD star trackers on opposite sides of the bus tracking a southern and a northern star to avoid use of gyros.

(7) Addition of downlink relay capability and doppler tracking of probe signals.

(8) Simultaneous playback of all seven tape recorder tracks to minimize head and tape wear.

B. Configuration

The Mars Polar Orbiter/Penetrator (MPOP) spacecraft is basically the Viking Orbiter design, with three readily apparent modifications: (1) a penetrator package has been added, (2) a different science complement is included, and (3) the propellant tanks have been stretched to accommodate trimming to a circular 1000-km, 2.46-h orbit. Table 1 lists the design baseline for each subsystem and major assembly. The injected spacecraft mass of 3357 kg is broken down as shown in Table 2.

Table 1. MPOP design base

Subsystem/assembly	Design base
Structure	Viking (modified)
Radio frequency	Mariner Jupiter/Saturn (modified)
Modulation/demodulation	Viking
Power	Viking[a]
Solar array	Viking
Batteries	Viking
Computer command	Viking[a]
Flight data	Viking (modified)
Attitude control	Viking
Star trackers	New
Pyrotechnics	Viking[a]
Propulsion	Viking (modified)
Mechanical devices	Viking (new)
Articulation control	Viking (new)
Data storage	Viking (modified)
S- and X-band antennas	Viking
High-resolution imaging (narrow-angle)	Viking
Synoptic imaging (wide-angle)	New
IR multichannel radiometer	Nimbus (new)
Radar altimeter	New
Gamma-ray spectrometer	Apollo (new)
Ultraviolet photometer	New
IR-VIS spectrometer	New
Relay radio	Viking (new)
Relay telemetry	Viking
Relay antennas	Viking

[a] Minor modifications to output switching functions.

The basic MPOP spacecraft has the Viking Orbiter eight-sided bus with four double-folded solar panels (Fig. 2). Additional packaging volume is obtained by relocating the N_2 gas bottles inboard. The six penetrators are launched individually, and the penetrator structure is designed for jettison prior to orbit circularization. Two relay antennas are included for both redundancy and improved relay communication coverage without spacecraft orientation maneuvers.

C. Telecommunications

The telecom design uses S- and X-band frequencies plus UHF for spacecraft-to-penetrator relay communications.

Table 2. MPOP spacecraft mass summary

Subsystem		Mass, kg
Structure		224.7
Radio frequency		32.5
Modulation/demodulation		7.8
Power		129.4
Command computer		17.4
Flight data		16.6
Attitude control		146.1 (includes 45 kg of N_2)
Pyrotechnic		4.9
Cabling		56.2
Propulsion		254.0 (less propellants but including 6 kg pressurant)
Devices		42.3
Articulation		9.5
Data storage		28.6
S/X band antennas		4.6
Relay radio		12.0
Relay telemetry		4.1
Relay antenna		4.3
Science		97.0
Gamma-ray spectrometer (including boom)	16.0	
Radar altimeter	12.0	
High-resolution imaging	45.0	
Synoptic imaging	5.0	
IR-VIS reflection spectrometer	6.0	
IR multichannel radiometer	7.0	
UV photometer	6.0	
	97.0	
Spacecraft dry mass (without propellants)		1092.0
Propellants		1852.0
Spacecraft (without penetrators)		2944.0
Penetrator system		413.0
6 penetrators	361.8	
Structure	15.0	
Contingency	36.2	
	413.0	
Injected mass		3357.0
Spacecraft adapter		70.0
Launch mass		3427.0 kg

The S- and X-band design is identical to that of Mariner Jupiter/Saturn 1977, with S-band reception/transmission possible over the low- or high-gain antennas and X-band transmission only over the high-gain antenna.

Data transmission will be at a maximum of 112 kbps, which will be used to obtain the high volume of imaging data. The expected X-band link performance, assuming a bit error rate of 2×10^{-2} uncoded, is 112 kbps. Coding is not assumed, since the Viking Orbiter block coder is not compatible with the anticipated ground data system. S-band is available for cruise engineering telemetry or as a backup for science data, although its data rate capabilities are approximately a factor of ten lower than X-band.

S-band frequency is used for Earth-to-spacecraft transmission. This uplink can contain ranging modulation and/or command modulation. Commands are transmitted at 4 bps, with an error rate less than 10^{-5} per bit.

Relay communication with the landed penetrators is accomplished via a UHF (~380 Mhz) link. Uplink reception of penetrator transmissions utilizes the relay antenna, receiver, and bit synchronizer used on Viking, modified to allow one-way doppler extraction, which facilitates penetrator location. Downlink command is UHF and is of a new design. The commands will be used to select penetrators for uplink transmission and for programming upcoming sequences in their memories. Both the uplink and downlink elements on board the spacecraft are implemented redundantly.

D. Data Handling

The data handling design incorporates both real-time and nonreal-time data recovery. Nonimaging science (including 1-kbps engineering telemetry as an option) is recorded and/or transmitted in real time at 8 kbps. The 2.112-Mbps narrow-angle imaging data are recorded on seven tracks, each at 2.112 Mbps/7 = 301.7 kbps, exactly as in the Viking Orbiter design. The 20-kbps wide-angle imaging data are transmitted in real-time only. In the event that a higher-resolution coherent radar system is adopted, the data can be recorded at rates up to 2 Mbps using a multi-track approach as for the high-resolution imaging. The proposed radar altimeter returns data in real-time at 4 kbps. Detected relay data from the penetrators can be recorded and/or transmitted in real-time (feedthrough mode).

As on the Viking Orbiter, two data subcarriers are used. The low-rate engineering telemetry is always present on the low-rate subcarrier. Any of the high-rate real-time science data noted above, tape recorder playback data, or real-time feedthrough penetrator data may be selected for the high-rate subcarrier when it is operational.

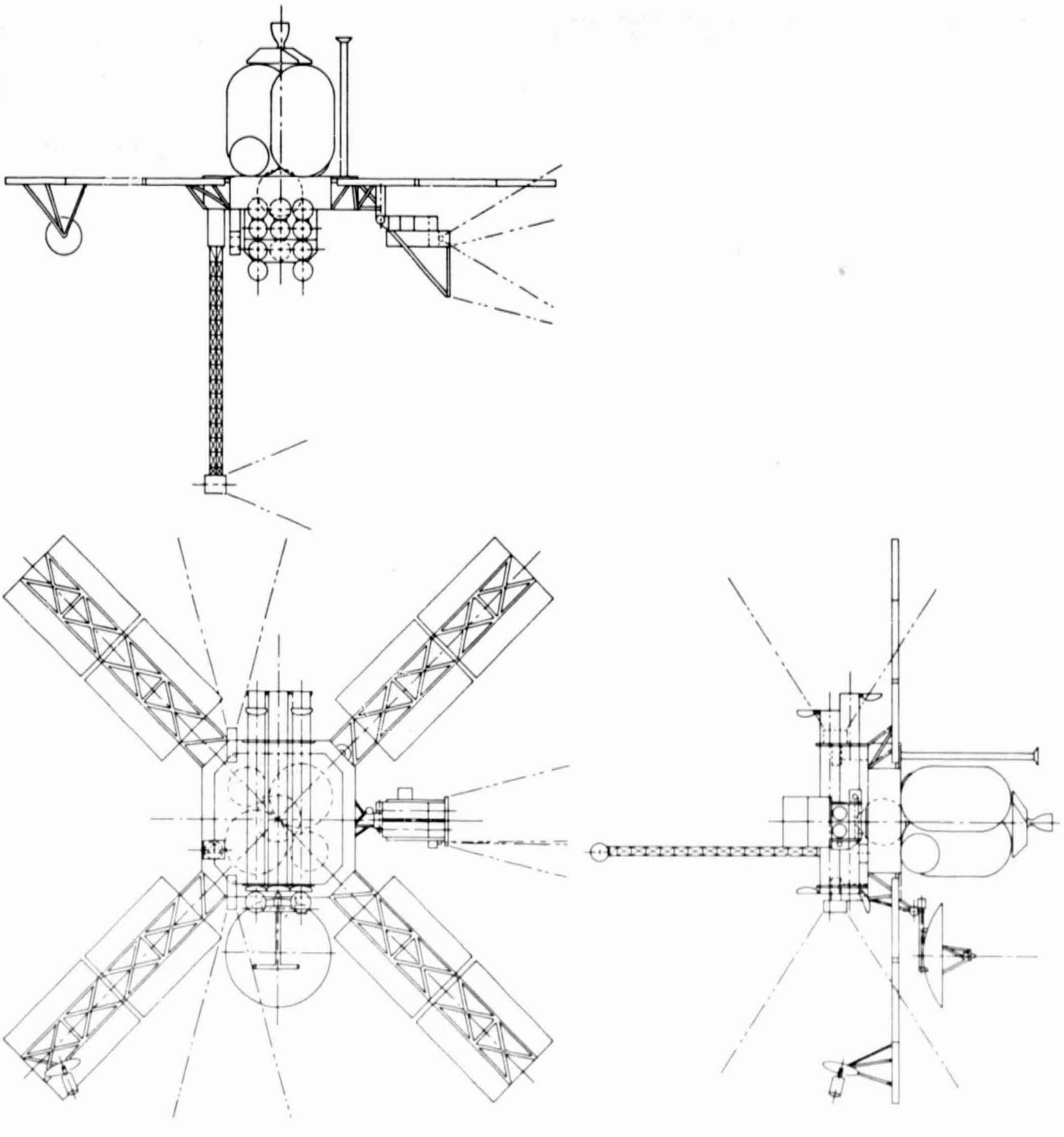


Fig. 2. Three views of the MPOP spacecraft

The Viking Orbiter tape recorder electronics are modified so that narrow-angle imaging, recorded on seven tracks at once, may also be played back from seven tracks simultaneously. In order to overcome slew-induced phase differences among the seven tracks, the data from each track are frame-synchronized and identified for later sorting and reconstruction during ground data processing.

E. Penetrators

The science instruments are mounted inside the cylindrical body of each penetrator. The approximate cylinder volume available for science is about 2500 cm^3 (7.6 cm in diameter by 56 cm long). Instruments can look out through holes in the wall of the penetrator or they may be extended so as to contact the soil.

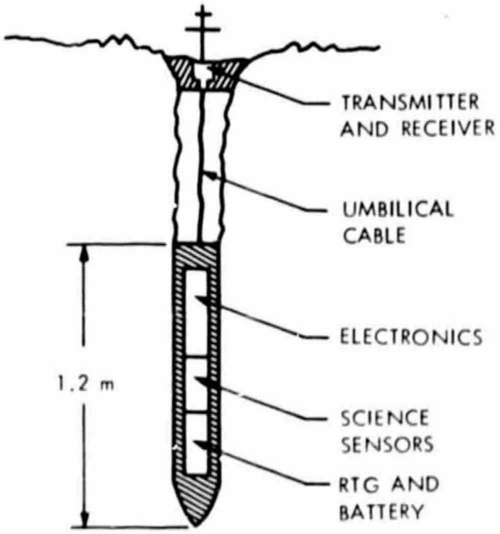


Fig. 3. Penetrator after coming to rest below the surface

The penetrator experiences as much as 1800 g deceleration as it comes to rest, and the final penetration depth is 1 to 15 m below the surface (Fig. 3).

Heat and power are provided by radio-isotope thermoelectric generators.

Experiment data are stored in the penetrator memory as they are collected. Once each 24 h, when the bus spacecraft passes overhead, the data in the penetrator memory are transmitted to the bus and relayed to Earth.

Experiments are operated by a penetrator sequencer controlled by commands from Earth (relayed through the bus).

IV. Mission Options

With an additional increase in the size of the spacecraft propulsion tanks, two of the probes could be released from a circular orbit. From the lower orbit, any point on the planet could be reached by the probes, providing greater science flexibility. However, there are unsolved technical problems related to the increased retro ΔV (210 versus 80 m/s for deployment from the eccentric orbit) that would need to be applied to the probes. The size of the solid motor and launch tube length and strength would all have to be increased.

The Mars launch opportunity beginning at the end of 1983 is less favorable than the 1981 opportunity studied and leads to higher C_3 and V_∞ values. An examination of the effect of these increases indicates that, using the Shuttle/IUS, the mission would still be feasible.

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