c240

NASA TECHNICAL MEMORANDUM

NASA TM-73,243

(NASA-TM-73243) MARS SURFACE PENETRATOR: SYSTEM DESCRIPTION (NASA) 88 p HC A05/MF A01 CSCL 03B

N77-32060

Unclas
G3/91 46232

NASA TM-73,243

MARS SURFACE PENETRATOR – SYSTEM DESCRIPTION

Edited by Larry A. Manning

Ames Research Center
Moffett Field, Calif. 94035

June 1977

Mars Surface Penetrator

System Description

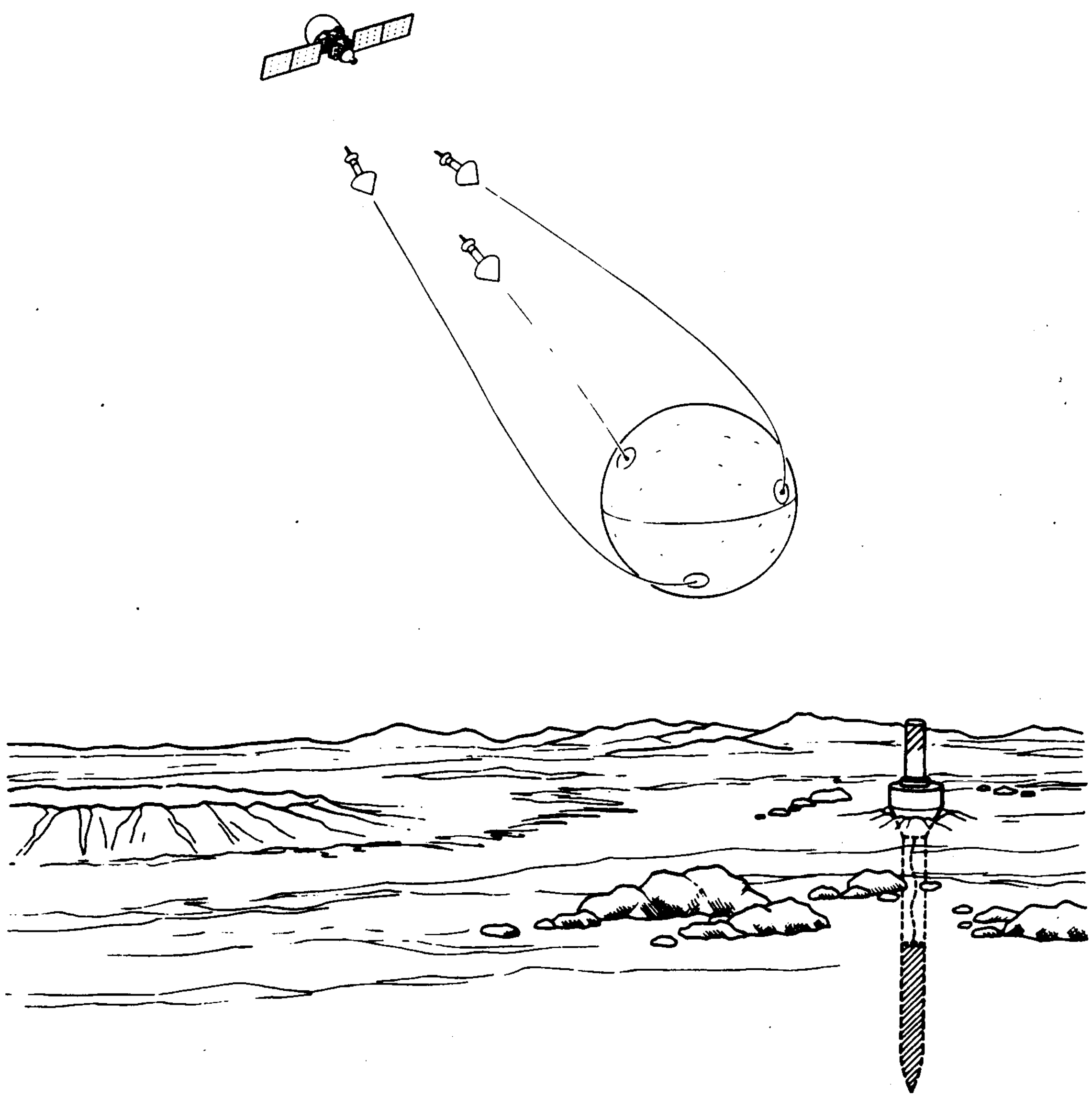


TABLE OF CONTENTS

missing

CONTRIBUTORS

Larry A. Manning	Study Leader/Editor
M. B. Blanchard	Science/Payload
T. E. Bunch	Site Selection
T. N. Canning	Systems/Experiments
D. M. Chisel	Systems
W. C. Coombs	Antenna
M. G. Dix	Experiments/Data Handling/ Power
T. L. Grant	Communications
R. Greely	Site Selection
R., W. Jackson	Mission/Survivability
R. B. Morrison	Survivability
V. R. Oberbeck	Science/Survivability
H. Shade	Science

MARS SURFACE PENETRATOR — SYSTEM DESCRIPTION

Edited by

Larry A. Manning

Ames Research Center

SUMMARY

A Penetrator network is vital to a geophysical understanding of Mars and an invaluable adjunct to an Orbiter/Rover combination in an intensive study of Mars. This report presents a point design of a Penetrator system for a 1984 Mars mission. The point design, including the strawman payload and its derivation from a geophysical science rationale, is described. The subsystems used in the point design are a combination of tested and conceptual designs. The data handling and communications plans are presented to allow consideration of the requirements placed by the Penetrator on the Orbiter and ground operations. While elements of the concept still need extensive testing in simulated mission environments, the point design provided in this report is technically feasible and the payload scientifically desirable.

INTRODUCTION

The Space Science Board of the National Academy of Sciences has recommended that surface Penetrators be considered as standard tools for exploration of the solar system (ref. 1). A number of studies (refs. 2-19) have concluded that surface Penetrator missions to Mars would provide useful scientific results and aid site selection for a sample return mission. During FY 1976, NASA Headquarters funded three activities designed to assess the feasibility of using surface Penetrators to emplace useful scientific experiments on the Martian surface: (1) Dr. James Westphal was appointed to chair and select an ah hoc committee of scientists to evaluate the usefulness of Penetrators as devices to explore Mars and other planets. (2) Selected investigators performed feasibility studies of candidate scientific instruments potentially capable of operating from Penetrators. (3) Ames Research Center performed a field test program to evaluate Penetrator systems, penetration depths, and environmental effects of penetration into terrestrial analogs of Martian surface materials. This effort was divided into two principal activities: (a) A contract with Sandia Laboratories for testing instrument components in the laboratory and Penetrators in the field; and (b) analytical studies performed in the Ames Space Science Division laboratories on contamination of impacted rocks, site selection, and penetrability. The Westphal committee strongly endorsed the penetrator concept for exploration of the solid bodies of the solar system and made specific recommendations for a Mars Penetrator mission (ref. 20). The instrument feasibility studies and field tests verified the functional capability of Penetrators as a useful science tool and identified areas requiring further testing (ref. 21).

This report shows the feasibility of Penetrators for planetary exploration with emphasis on a point design for the 1984 Mars mission. The information contained in this report is derived from studies at Ames, communication with participating scientists, and results from the extensive use of Penetrators by the military. Issues of immediate interest for planning such a mission are covered. Penetrator science strategy is recommended based upon a two-launch mission, each launch consisting of three Penetrators, a geochemical Orbiter, and a Rover with a deployable science package.

The Penetrators' role in establishing a network of stations for defining the global nature of Mars and its meteorology is emphasized. The purpose for making scientific observations from widely separated sites is described both from a direct interest in an increased understanding of Mars and as a reconnaissance leading to site selection for a sample return mission. A Penetrator system is the only currently viable option for such an exploration network.

Discussions are included to illustrate possible targeting strategies for a set of six Penetrators, and a strawman scientific payload is described which will accomplish the outlined science objectives. The Penetrator point design is described and the subsystems are delineated in terms of power, mass, volume, data, and functional modes. The prospects for survival of the rigors of emplacement are described. The operation of the Penetrator is discussed sufficiently to illustrate the manner of control during the mission and to indicate the principal requirements which the network will place on the relay Orbiter.

SCIENCE RATIONALE

Overview

The goal of planetary missions, in general, is to gather data which will help in understanding the formation, evolution, and present state of planetary bodies. Planetary bodies are complex and are characterized by both surficial and interior inhomogeneities. Even verifying the existence of such features can often provide useful information. Quantitative measurements of key physical properties at the surface taken from a network of sites distributed over a planet's surface can provide a data base for constructing a composite picture of that planet. Further, such a network provides simultaneous measurements of transient phenomena of the planet's interior, surface, and atmosphere. A network of complementary stations is the only way to obtain meaningful time-position data which will allow formulation of sound working hypotheses as well as the capability to evaluate competing hypotheses.

The feasibility of the Penetrator concept has been evaluated by the Westphal committee (see ref. 20). This committee concluded that experiments performed from a network of Penetrators can provide the basic and essential facts needed to begin understanding the evolution, history, and nature of another planetary body. The Terrestrial Bodies Science Working Group (TBSWG) defined "network science" as a set of systematic measurements over a relatively long time duration (one year minimum) at several widely distributed locations over a planet's surface. The measurements should necessarily include seismic, meteorologic, geochemical, and imaging experiments. Experiments to measure heat flow and detect water are also very desirable. Some of these measurements should be performed simultaneously (e.g., seismic, meteorologic, and imagery). The Mars subgroup report from TBSWG discusses the value of these seven measurements, and it was concluded that they can be effectively performed from a network of Penetrators (ref. 22).

There are four principal scientific reasons for using Penetrators to deploy experiments on Mars. First, because a number of Penetrators can be deployed at widely separated places on the planet during a single mission, they can establish a network of stations to measure geophysical, meteorological, geochemical, and morphological phenomena. Second, Penetrators can emplace experiments beneath the surface to obtain measurements at greater depths than are possible by either soft or hard Landers. Third, Penetrators can provide important information on site selection for a Mars sample return mission. Finally, Penetrators can reach areas that cannot be reached by larger, more sophisticated soft Landers due to mission safety constraints.

Network Science Experiments From Penetrators

The presently defined 1984 mission to Mars specifies a dual launch, each of which includes an orbiting spacecraft, a roving vehicle with one deployable science package, and three Penetrators equipped with experiments to provide network science. Once deployed, the global network will include eight stations — six Penetrators and two deployable packages from the Rovers. The three principal experiments for this network are seismology, meteorology, and magnetometry.

Seismology— While it may be possible to deduce some features of the interior structure of Mars from one seismometer with a very large Mars quake, a network of as many as 12 seismometers (ref. 21) at widely separated locations would be desired to accurately determine the interior structure of the planet. Six Penetrators can provide a network of seismometers which can monitor simultaneous Mars quakes from the onset of the mission; and the two seismometers in the deployed science packages from the Rovers will later increase this network to eight stations, thus obtaining a near optimum network.

Seismometers can be emplaced in the regolith with Penetrators as a natural consequence of the impact landing process. When emplaced in this manner, they have the advantage of being well coupled to the Martian regolith. By contrast, the Viking II seismometer, mounted on the Lander, is affected by vibrations induced by wind and thermal transients. Consequently, a high noise level predominates whenever increased meteorologic activity occurs. These problems can be avoided if seismometers are emplaced beneath the surface with Penetrators.

Meteorology— A global network of meteorological experiments is mandatory for understanding the seasonal variations in atmospheric processes. This network, consisting of experiments carried on board the afterbody of a number of Penetrators, can provide basic information on atmospheric circulation, the physics of important atmospheric processes, the nature of important small-scale local phenomena, and the observations of surface processes.

The essential measurements include pressure, temperature, wind speed, and direction. These measurements will allow the global atmospheric circulation processes to be defined. Estimates of transport rates may be possible from a combination of these measurements and Orbiter data. Other highly desirable measurements include relative humidity, atmospheric turbidity, and soil movement. Relative humidity will provide much needed knowledge related to the seasonal and diurnal water cycle and the interaction of water with the regolith. The atmospheric turbidity measurements will assist in the interpretation of Orbiter data for the study of dust cloud formation and will provide a basis for determining size, shape, and composition of the suspended aerosols. Soil movement measurements will be used to study erosion rates and weathering processes.

Magnetometry— A network of magnetometers on the surface of Mars can provide information required to define magnetic fields and vectors and to differentiate between internally generated fields and those induced by the interaction of the ionosphere with the solar wind. While one magnetometer permits estimation of the properties of an assumed dipole field, several magnetometers when used with orbiting magnetometers permit offsets, inclinations, and deviations from a simple dipole to be determined. An internal dipole field, if present, can be described from these measurements, and models of the planet's interior electrical conductivity can be deduced.

Site Characterization Experiments From Penetrators

Only the Viking I and II soft Landers have sampled the Martian surface. Similar geological environments were observed at both sites. However, Mars exhibits a diverse assemblage of geologic terrains. It is imperative that the next mission sample as many of these terrains as possible in an attempt to examine the diverse characteristics of the planet's crust. Knowledge of the crustal structure and composition will provide crucial information on the geological evolution of the planet's surface and can be obtained by sampling beneath the wind blown overburden materials. The five principal experiments for site characterization are geochemistry, water detection, heat flow, stratigraphy, and imagery.

Geochemistry— The most important reasons for studying subsurface chemistry are to obtain in-situ analysis of bedrock formations and to determine differences between surface and near-surface geochemistry (ref. 20). Both aeolian and impact cratering processes mix materials of the regolith. Chemical weathering also modifies the surface of the original crustal materials. The diversity of terrain types on Mars (cratered terrain, polar ice caps, young volcanic complexes, chaotic terrain, and laminated terrain) suggests considerable heterogeneity in minerals and elemental composition should exist in some locations. It appears the crust is now covered by a well mixed and perhaps homogenized regolith, since similar bulk chemical compositions have been obtained at both Viking I and II sites. It is, therefore, desirable to sample beneath the overburden in order to interpret the diversity of landforms observed on Mars and to gain an understanding of the geologic evolution of the planet. Penetrators are ideal for this purpose because they can penetrate beneath the surface of wind-blown deposits and meteorite impact deposits and, thus, reach bedrock.

Water— A major aspect of Martian exploration is the search for evidence of life. The presence of water at a given site enhances the likelihood that the site is, or was, a habitat for life. The location of water is important for geological and geophysical reasons. For example, surface features observed in photographs taken by Mariner 9 and Viking Orbiter (ref. 23) suggest, but do not prove, that water flowed on the Martian surface at some time in the past, even though current Martian conditions are not favorable for liquid water. A major question concerns the amount of water stored in the regolith as permafrost and mineralogically bound water. Answers to these questions could clarify the origin of surface channels and provide clues to when an atmosphere existed and why conditions have changed. Subsurface measurement of free and bound water is possible by emplacing water detection experiments beneath the surface with Penetrators.

Heat Flow— Martian heat flow measurements may be possible from Penetrators. Since thermal gradients can vary widely over the planet's surface, it is desirable to measure these gradients in as many sites as possible to obtain meaningful planetary heat flow values. The thermal inertia maps produced by the Viking infrared mapping radiometer will be essential to locate possible prime landing sites for heat flow measurements. Because diurnal and seasonal temperature waves from the planet's surface interfere with thermal gradient measurements, these gradients should be measured as deep in the regolith as possible. Penetrators provide the only possibility of making heat flow measurements beneath the influence of the diurnal and seasonal temperature waves. Heat flow modeling studies (ref. 24) and laboratory experiments (ref. 25) show that planetary heat flow measurements are feasible even though Penetrators produce artificial thermal effects during the impact process. Of considerable value, as well, will be measurements of the thermal properties of the regolith materials.

Stratigraphy— Penetrators offer the only method for studying subsurface stratigraphy. It is certain that a major question for future exploration of the near-surface crustal structure of Mars will be (ref. 26): How much have the aeolian and impact processes contributed to the production of the regolith? The survival of crater ejecta blankets may provide clues on the roles of aeolian and impact processes forming the regolith on Mars. Each Penetrator will carry an accelerometer that will allow the thickness of crater ejecta and wind-blown deposits to be deduced.

Many tests of Penetrators impacting terrestrial materials have been performed (ref. 27) in which stratified deposits have been penetrated. The accelerometer records show a discontinuous change in deceleration occurs as the Penetrator passes from one sediment type to another. This data indicates an obvious application to study near-surface stratigraphy of the Martian regolith. For example, if geochemical experiments detect bound water in clay minerals, then these measurements can be associated with changes in penetration resistance through interpretation of accelerometer records to verify different depositional environments.

Imagery— A camera on the afterbody of a Penetrator can provide the opportunity to study the surface geology, the interaction between the surface and the atmosphere, and transient meteorological events. In addition, imagery can provide information on local morphology which can aid in interpreting the data from other experiments (e.g., seismometer, heat flow, geochemistry, stratigraphy). Imagery of surface terrain would be divided into near- and far-field observations. Near-field observations would include soil characterization (particle size, layering, weathered zone), cratering (areal density), aeolian processes (erosion), and condensates (H_2O and CO_2 ices). Far-field observation would include site characterization, dust storm activity, and condensate cloud activity.

The Penetrator's Role in the Long-Range Exploration of Mars

Penetrators may be required in order to satisfy the overall scientific strategy for exploration of Mars. The Space Science Board of the National Academy of Sciences defined a major long-range objective for the exploration of Mars as the return of a sample to Earth (ref. 28). A review of the sampling strategy used for Apollo missions points out that the most valuable materials to be returned from Mars will be samples taken from bedrock.

Even before Apollo, it was known that the lunar regolith was an impact-shattered blanket containing material from distant places. However, because of safety constraints, the Apollo 11 astronauts returned samples only from a 17- by 20-m area of the lunar regolith near the landing module which was more than 400 m from the nearest crater that had excavated bedrock samples. No samples of bedrock were returned on that mission. Later Apollo missions sampled ejecta from impact craters that had penetrated bedrock, thus enabling chemical, chronological, and petrological studies to be performed to determine the conditions at the time of formation of the rocks. Although there are suspected outcrops of bedrock some distances from the Viking I Lander, it cannot be sampled. Viking II also failed to sample bedrock. Sampling the surface of Mars has not advanced beyond that for the Moon at the time of the Apollo 11 mission. To obtain meaningful samples for laboratory study on Earth, it will be necessary to follow the strategy defined by the 1965 summer study on lunar exploration and obtain in-situ measurements of bedrock before a mission to return Martian samples is launched.

A series of Penetrators can provide key information to optimize site selection for a sample return mission. An optimum soft landing site for a sample return mission is that site having the thinnest regolith because it has the highest probability for collecting bedrock material. Because each Penetrator will carry an accelerometer, in addition to its complement of geophysical and geochemical experiments, which records the deceleration during the impact event, a comparison of accelerometer records of many Penetrators will show which area has the thinnest regolith and thus, offers the greatest potential for return of a bedrock sample.

Summary of Penetrator Advantages

The principal scientific reasons for using Penetrators to deploy science experiments on Mars are the following: (1) They can establish a network of stations to measure seismic, magnetic, and meteorologic phenomena over widely scattered regions on the planet's surface; (2) They can emplace experiments beneath the surface; (3) They can provide for measurements of geochemical, heat flow, and morphologic observations over regions on the planet's surface that could not be reached by larger, more sophisticated soft Landers; and, (4) They can provide important information on site selection for a Mars sample return mission.

There are also inherent advantages for the following science experiments when performed from a Penetrator:

(a) *Seismic*— More network stations are possible, and superior coupling to the ground will enable measurement of a broad spectrum of seismic events free from noise produced by solar radiation and meteorologic activity.

(b) *Magnetic*— More network stations are possible so that deviations from a simple dipole can be determined for the planet's internal magnetic field.

(c) *Meteorologic*— More network stations are possible for acquiring contemporaneous measurements of wind direction, velocity, atmospheric pressure, and humidity. When data from the meteorology experiment is combined with image observations of transient events over widely scattered regions, a broader understanding of the atmospheric processes can be gained.

(d) *Geochemical*— Elemental analyses will be more meaningful when performed from a Penetrator because measurements may be performed on coherent formations beneath the wind-deposited overburden. Two rock or sediment samples may be possible; one from surficial overburden captured upon entering the ground, the other from the depth at which the Penetrator stops. The surficial analysis would be used to correlate with the Orbiter's multispectral and γ-ray spectrometer mapping data. The analysis of sediment obtained from depth would be used to correlate with the stratigraphic information.

(e) *Water detection*— Measurements of free and bound water from layered sediments meters below the surface can provide important information on the location and nature of stored water in the regolith (e.g., hydrated clay minerals, permafrost).

(f) *Stratigraphy*— Decelerometer data can provide the capability to characterize soil properties of layered sediments through which the Penetrator has passed.

(g) *Imaging*— Although the camera would not be as sophisticated as that possible on an alternate hard Lander, it could provide observations of transient meteorological and geological processes from more sites.

(h) *Heat flow*— Although the feasibility of this experiment is still being studied, the Penetrator offers the only possibility of making heat flow measurements by reaching depths below the influence of the diurnal and annual temperature fluctuations.

MISSION PROFILE

Overview

Prelaunch— Before it is attached to the Bus spacecraft, each Penetrator system will be assembled and checked out. If sterilization is required, each Penetrator system will be subjected to terminal sterilization after assembly.

Each Penetrator system will be attached to the Bus spacecraft in a bio-shield launch tube. Since the RTG will be installed during final assembly, each penetrator will be powered and special cooling may be required for each Penetrator to dissipate heat from the RTG. Housekeeping information will be acquired by the Orbiter through an umbilical connection.

Launch to separation— During the December 1983-January 1984 launch opportunity two spacecraft are to be launched using the Shuttle/IUS two-stage vehicle. Each spacecraft consists of a geochemical Orbiter, a Rover with a deployable science package, and three Penetrators. The spacecrafts have successive 14-day launch windows.

The spacecrafts are injected into type II interplanetary trajectories requiring about nine months transit time. Arrival times would be during September-October 1984 with arrival date separation of the spacecrafts being 16-26 days depending upon the launch times. This arrival time period is about one month before Mars perihelion and nine months before superior conjunction. A type IV interplanetary trajectory is also being considered since it significantly reduces the approach speed. The associated longer trip time means arrival would occur between the dust-storm periods.

The Orbiter attitude is three-axis celestially referenced during cruise. The Penetrators will be monitored during this time with their housekeeping data transmitted to the Earth by the Orbiter. Near-Earth and Mars approach midcourse guidance maneuvers are executed to remove injection errors and to target for final approach. Voyager-type S/X radio data and optical approach data are used to generate navigational information.

The point design calls for separation of the Penetrators from the spacecrafts on the hyperbolic approach trajectory at least two days and as much as 1 week before arrival. The Penetrators are targeted individually with the spacecraft turning to properly orient each Penetrator for the propulsive separation maneuver. Separation involves a sequence of actions including opening the launch tube covers and firing the deployment motor. The Bus will provide power and sequencing for the separation activities.

After separation of all Penetrators, the spacecraft (Orbiter/Rover) would be targeted for orbit insertion. One spacecraft would be placed in a near-polar orbit and the other in a low-inclination (about 35°) orbit for equatorial landing zone coverage.

Post Separation— After separation, each Penetrator will independently enter the atmosphere, land, and erect its communication antenna. All measurements of impact acceleration and initial instrument operations will be stored on board the Penetrator. Normal operation of the Penetrator will be to store all data for each sol on board and transmit the stored data to the Orbiter during the communications session. Penetrator communications will be timed by an on-board timer which can be reset by command from the Orbiter. The Orbiters would be used as a data and command relay for Penetrator operations as directed by the Principal Investigators.

Separation Alternatives

Two separation opportunities arise during the mission for placing the Penetrators in the desired array patterns relative to one another and to the Lander-Rovers. In the first mode, the point design baseline, the Penetrators are targeted and separated several days before orbit insertion; in the second mode they are separated and targeted while the Orbiter is in an elliptical parking orbit.

Approach mode— When the approach targeting mode is used, the spacecraft is oriented as required, and the Penetrator is launched from its planetary quarantine launch tube using the self-contained solid propellant rocket. The area on Mars accessible by this means is a circular band between 66° and 76° from the point where the extension of the hyperbolic approach velocity vector through the center of Mars exits the surface. These angles are determined from the requirements that the inertial flight path angle at atmospheric entry be at least 10° to avoid skipout but less than 15° to assure acceptable heat loads on the decelerator. This option is illustrated in profile in figure 1.

The latitude of the point about which the band is centered is given by tha arrival declination which varies from -26° to -38° as determined by early and late launching on the type II trajectory. For early launch, impact at any latitude from +50° to -87° is possible; for late launch, the range is from +38° to -75°. The longitudinal position of the targeting band is established by the arrival time (i.e., the hour of the sol).

For a type IV trajectory from Earth the circular band is 600 km (10°) wider (due to the slower approach speed), and landing can occur within 57° of the extended hyperbolic approach vector. Arrival declination is +8° for an impact latitude range from +85° to -69°.

Orbital mode— When the Penetrators are targeted from elliptical orbit, the Orbiter is oriented in the same manner as for the approach targeting, and the self-contained rocket motors are fired. The available targeting area is a narrow band (a few hundred kilometers wide) centered about the subsatellite trajectory and extending from 12° to 40° from the subperiapsis point as shown in figure 2. Entry angle constraints are not as severe as for the approach mode due to the lower entry speed ($-9° > \gamma_e > -23°$). Initially, the longitude of subperiapsis will be fixed by the arrival declination and selected orbit inclination; however, with delayed separation, selection of a slightly non-Mars-synchronous orbit permits targeting to any longitude.

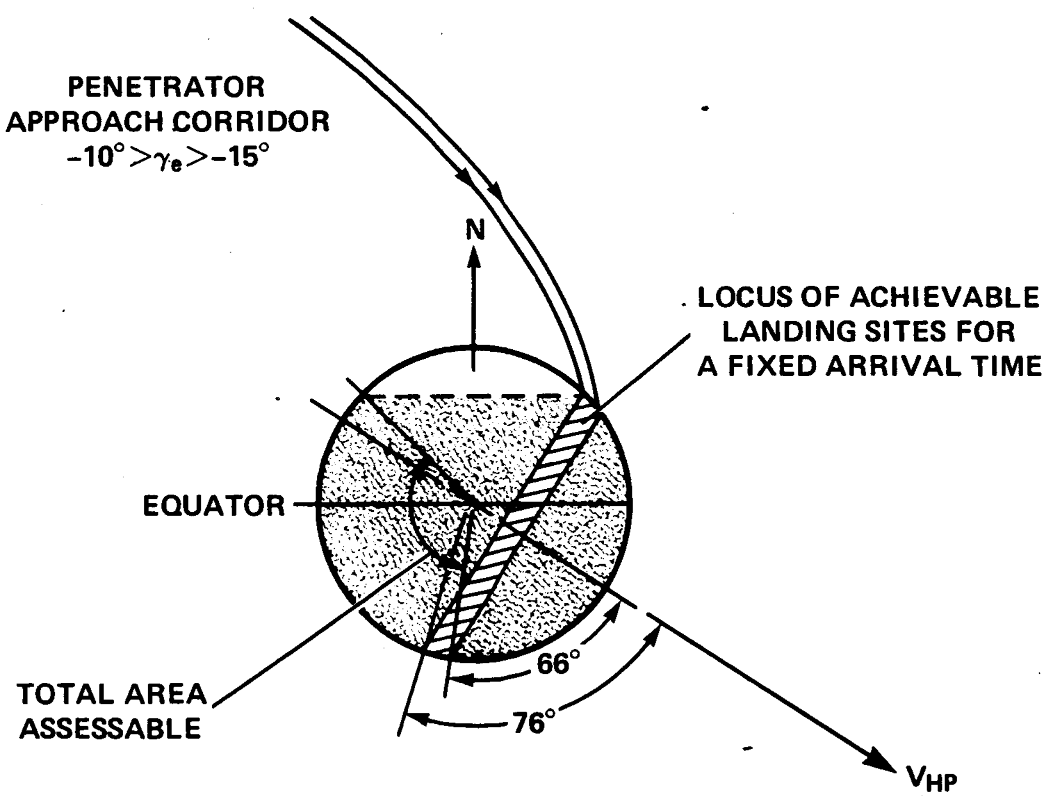


Figure 1.— Targeting from approach.

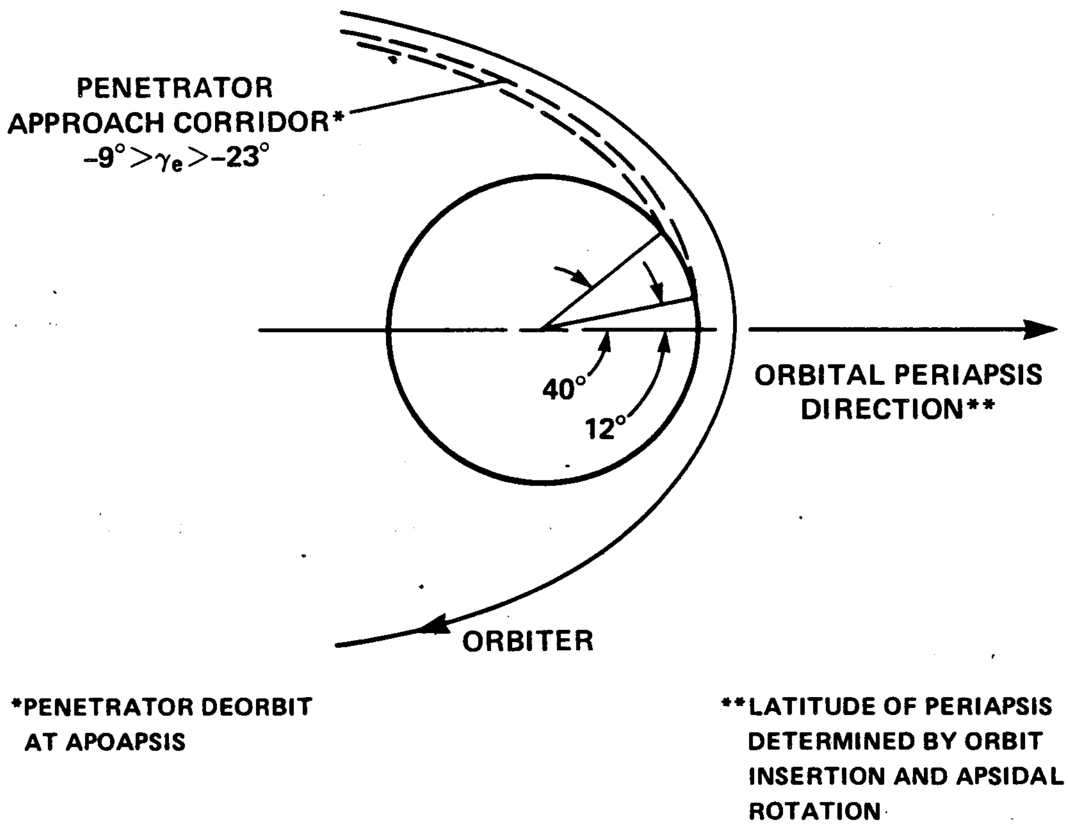


Figure 2.— Targeting from orbit.

SITE SELECTION

A Penetrator global network can provide seismic, magnetic, meteorological, and heat flow stations; ground truth for orbiting γ-ray spectrometer and multi-spectral imaging systems; and on-site geochemical, geological, and surface imaging data. This example of site selection is an exercise to show how sites may be evaluated and chosen within mission constraints and is consistent with the framework of the point design. Selection was made on the basis of science objectives, entry constraints, and potential instrument performance. The science objectives were discussed previously.

Engineering and geological information pertinent to site suitability was provided mainly from references 16 and 21, published results from studies of Viking I and II data, members of the Mars Science Working Group, and the Ames Research Center Penetrator team.

Entry Constraints

Targeting— The accessible latitudes were shown in the Separation Alternatives section to be +50° to -87° for an early launch and +38° to -75° for a late launch where a type II trajectory is used. The longitude can be varied from 0° to 360° by controlling the hour of arrival.

Altitude— The atmosphere entry aeroshell and descent velocity control subsystems deliver the Penetrator to near vertical flight (15° incidence or less) at 12 km above the zero datum. The impact speed is also controlled to the range of 135-165 m/sec down to -3-km altitude for proper penetration. This performance permits use of all but the highest peaks (i.e., about 0.1 percent of the surface). Allowing for uncertainties in topography of ±2 km narrows the acceptable altitude range to -1 to +10 km.

Landing site accuracy— Pointing accuracy and control of the separation ΔV maneuver result in a typical impact footprint of 100 km along the orbit path and 80 km cross range for separation on hyperbolic approach (see Guidance and Navigation section). On-orbit separation would significantly reduce these errors.

Terrain— Previous testing of a strawman Penetrator has shown acceptable penetration in 25 percent porous basalt and in moist loess (refs. 29-37). Even in softer material (i.e., dry loess) penetration should not exceed the 15-m unbilical length (ref. 38).

Slopes of up to 45 percent are expected to have successful penetration probabilities of nearly 100 percent. Steeper slopes will result in a decreased success probability although slopes up to 60 percent are anticipated to have a 50 percent success probability.

The question of hitting a boulder is treated in the Survivability section.

The Penetrator antenna will extend up to 1 m above the surface. Thus, for polar sites, the antenna might become covered with precipitated condensibles. Therefore, the limit on possible target sites will be placed inside the extremes of the annual variations of the polar caps (e.g., the layered terrain region). This would still permit close observation of polar cap phenomena and may be within a region of very high soil thermal conductivity, thus providing the maximum design challenge for the thermal control of the forebody.

Instrument Considerations

Seismic— To seismically characterize the interior of a planet both global and local networks are needed. A global seismic station network requires a minimum of four Penetrators combined with two Rovers spaced about 5,000 km apart. A local network requires three stations on the order of hundreds of km apart to provide (1) a fourth global station, (2) a confirmation of a seismic event, (3) a determination of apparent velocities for both near and far events, (4) a location of the epicenter, and (5) a shallow event network (ref. 39).

Magnetic— Deployment of three to four magnetometers at 3,000- to 5,000-km intervals coupled with the Rover deployed magnetometer packages can provide a quantitative measure of the internal field strength and origin (ref. 40).

Meteorologic— Optimum meteorological information requires one site near the equator for pressure variations, one between the Viking I and II sites, and at least one site near the 10°-20° latitudes. A longitudinal spread is also necessary to delineate circulation patterns. The clustering required for a local seismic network could also provide a determination of weather front direction.

Geologic and Biologic— A broad range of geologic sites are needed to provide geochemical and surface imaging data. In addition, consideration was given to selecting potential water bearing and biologically active sites. The Penetrator global geochemical network can provide ground truth for the orbiting γ-ray spectrometer; thus, Martian geologic units that comprise large regional areas have been included.

Representative Sites

The approach used is to key on the most important site that satisfies the entry constraints and as many instrument considerations as possible and is the most attractive in terms of scientific relevance. The Syria Rise (Tharsis Bulge) has been designated a key area, at least on a geophysical basis because several penetrators located close to this area can confirm a seismic event by simultaneous recordings and will establish a network to detect shallow events. With this as a starting point, four options are shown in table 1 as candidates for targeting. These options have been laid out on a latitude-longitude map in figures 3(a) and 3(b).

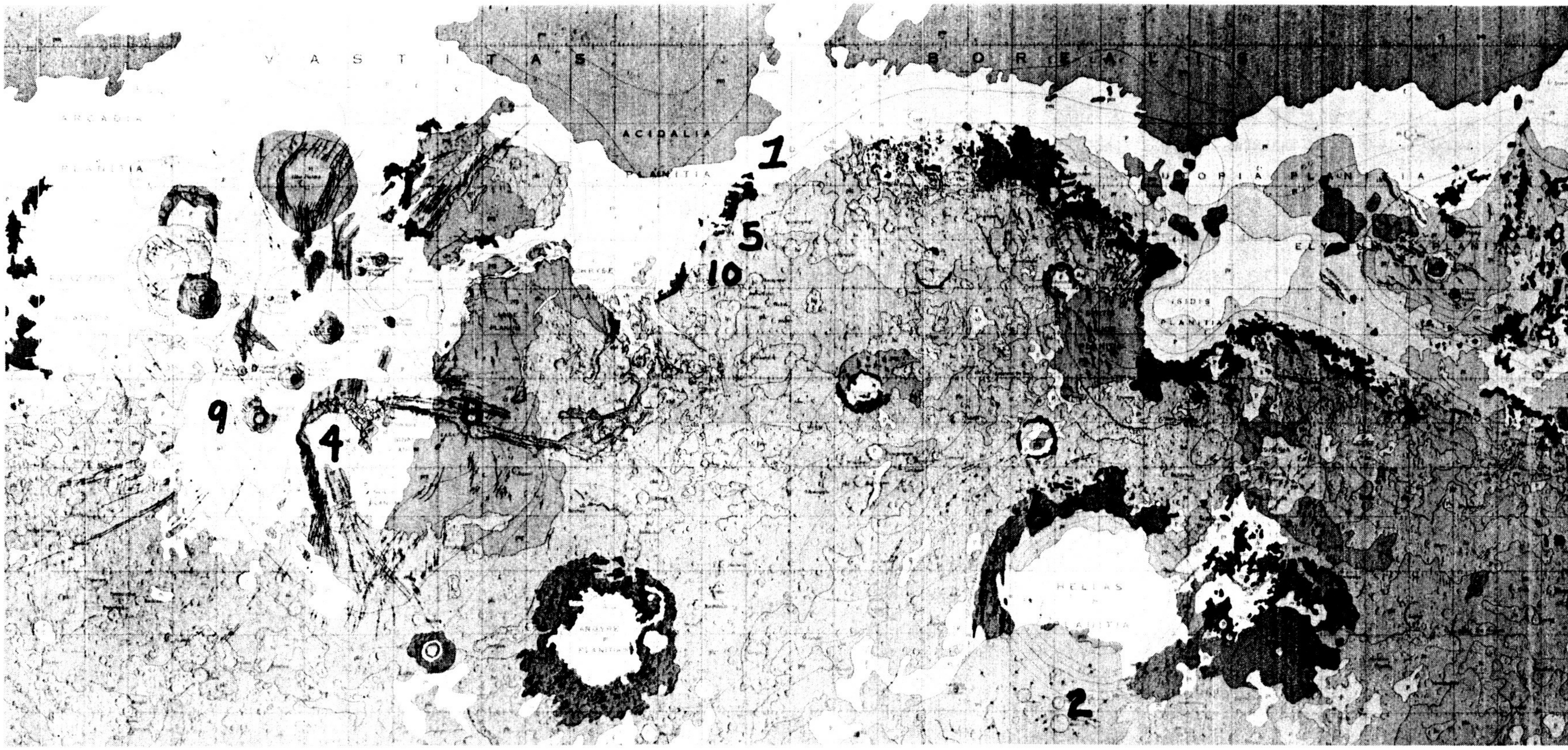
The impact sites described are intended to be indicative of what can be done and to be recommended selections. They are not limiting in any way. Numerous other selections could be made consistent with the hyperbolic approach geometry and the targeting constraints described. In order to facilitate such selection, overlays have been included for the equatorial and the south polar regions shown in figures 3(a) and 3(b). The equatorial overlay is aligned with the equator and then moved along it to represent different arrival hours. The polar overlay would be rotated about the pole. The overlays depict a continuous region within which the three Penetrators from a single spacecraft can impact the surface. Thus, once the equatorial overlay has been positioned, the position of the polar overlay is defined by observing the longitude of the central meridian of the impact ring on the equatorial map and orienting the polar overlay at the same longitude.

TABLE 1.— PENETRATOR IMPACT SITE OPTIONS (I, II, III, IV)

Launch time and penetrator number	Site: Identification (fig. ref.)	Site: Location Latitude	Site: Location Longitude	Altitude	Comments
OPTION I: A. Early launch Penetrator:1	Acidalia Planitia (1)	46° N	5° W	0 to -1 km	Peraglacial plains with aeolian deposits superimposed on volcanics. Would provide ground truth and imaging for Northern Hemisphere.
Penetrator:2	Amphitrites Patera (2)	59° S	297° W	+1 km	Volcanic terrain with low profile constructs and flows on edge of Hellas Basin. Ground truth for γ-ray spectrometer.
Penetrator:3	S. Polar region (3)	81° S	190° W	unknown 0 to +1 km	Bedded plains (laminated terrain). Good site for stratigraphic studies. A specially modified penetrator is necessary to cope with colder temperatures.
B. Late Launch Penetrator: 1,2, & 3	Syria Rise (Tharsis Bulge) Key area (4)	15° S	105° W	9.5 km	Volcanic plains covered with impact generated regolith, which is capped with thin aeolian deposits. Excellent site for seismic clustering and local network for shallow events.
OPTION II: A. Early launch Penetrator: 1,2, & 3	Syria Rise (Tharsis Bulge) Key area	15° S	105° W	9.5 km	Same as in B, Option I
B. Late launch Penetrator:1	Cratered highlands (5)	30° N	10° W	+1 km	Ancient cratered terrain covered with impact generated regolith. Two choices of units: (1) intercratered area, mantled; (2) intercratered area, nonmantled. Both units have extensive global coverage.
Penetrator:2	Hellas rim (6)	29° S	303° W	1-2 km	Ancient crustal material (basin rim). Good for early martian geologic history and geochemistry.

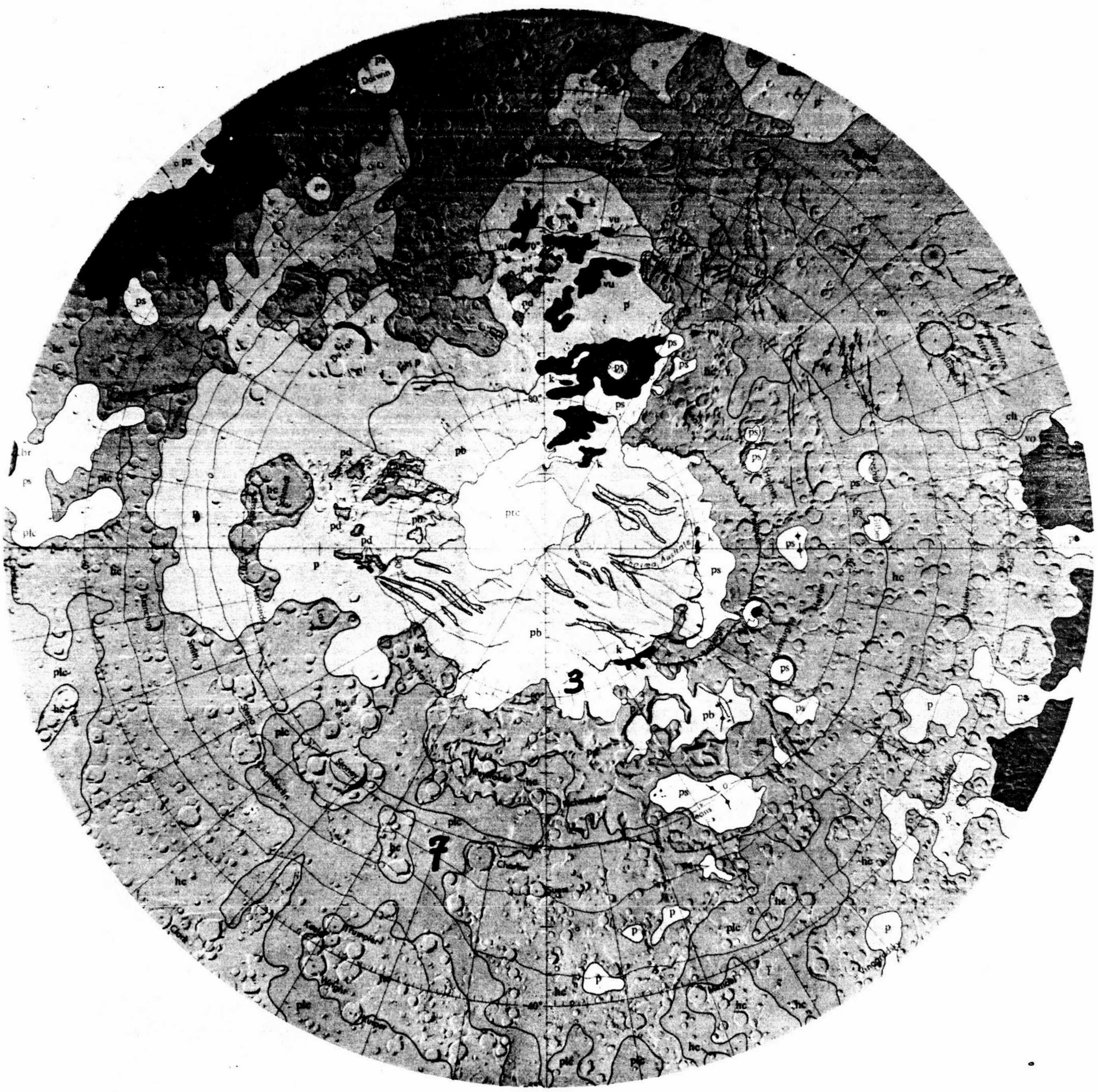
TABLE 1.- CONCLUDED.

Launch time and penetrator number	Site: Identification (fig. ref.)	Site: Location: Latitude	Site: Location: Longitude	Altitude	Comments
Penetrator:3	S. Polar cratered terrain (7)	68° S	160° W	+1 km	Highly cratered plateau (craters partly buried). Affords good ground truth of extensive martian unit and maximum spacing for global network.
OPTION III: A. Early launch Penetrator:1	Canyonlands (8)	10° S	73° W	2.5 km (flow)	Rough variable material containing mass wasted and possibly fluvial sediments.
Penetrator:2	Acidalia Planitia (N. Plains)	46° N	5° W	0 to -1 km	Same as Penetrator:1 in A, Option I
Penetrator:3	S. Polar region	81° S	190° W	unknown 0 to 1 km?	Same as Penetrator 3 in A, Option I
B. Late launch Penetrator 1,2, & 3	Syria Rise (Tharsis Bulge) Key area	15° S	105° W	+9.5 km	Same as in B, Option I
OPTION IV: A. Early launch Penetrators: 1 and 2	Syria Rise (Tharsis Bulge) Key area	15° S	105° W	+9.5 km	Same as in B, Option I
Penetrator:3	S. Polar region	81° S	190° W	unknown (0 to + 1 km)	Same as Penetrator 3 in A, Option I
B. Late launch Penetrator:1	Arsia Mons Plains S.W.(9)	8° S	130° W	+5 km	Volcanic plains surrounding Arsia Mons with fairly continuous aeolian mantle overlying impact regolith.
Penetrator:2	Cratered uplands (10)	25° N	15° W	+0.5 km	Mostly impact regolith developed in older volcanic plains and plateau materials. Good station for ground truth as this unit has large global coverage.
Penetrator:3	Amphitrites Patera	59° S	297° W	+1 km	Same as penetrator 2 in A, Option I.



(a) Equatorial region.

Figure 3.— Index map showing penetrator sites keyed to table 1. A total of 6 penetrators is available per option. The combination of sites is dependent on launch target band coordinates. See table 1. Maps for figures 3(a) and 3(b) were provided by David H. Scott and M. H. Carr, 1976.



(b) South polar region.

Figure 3.- Concluded.

STRAWMAN PAYLOAD

Potential Experiments

Several science disciplines have been proposed for experiments in the Penetrator payload. The most important of these are geophysical, meteorological, geochemical, and morphological. The Westphal committee and the Terrestrial Bodies Science Working Group recommended that all of these disciplines be represented in the payload, if possible, although it was recognized that mission objectives would determine priorities for the science experiments and the type of actual experiments designed.

Tentative performance characteristics for seven basic types of potential experiments for a Penetrator payload are shown in table 2. These performance characteristics were obtained in discussions with potential experiment investigators for each type shown. The design concept and performance characteristics for some of these experiments are reasonably well defined (e.g., seismometer, magnetometer, α-p backscatter/x-ray fluorescence, water vapor detector) because some investigators, during the last two years, performed feasibility studies on making measurements from a Penetrator environment (refs. 41-42). However, the design concept and performance characteristics for other experiments are not well defined (e.g., meteorology, imaging, differential scanning calorimetry or differential thermal analysis, γ-ray spectrometer, heat flow, and stratigraphy) because either feasibility studies are not complete or studies have not yet been performed (ref. 43).

Recommended Payload

For the current 1984 mission plan the Penetrators' key responsibility is to obtain measurements from a network of stations deployed around the planet to gain information about the interior and atmosphere that would not be obtained by an orbiting spacecraft or a roving vehicle on the surface. In this role the highest priorities are assigned to the network aspects (i.e., the geophysical and meteorological experiments) of the Penetrator. Only after accommodating those experiments (in terms of volume, power, and data storage) can the remaining types of experiments be included.

A strawman payload dedicated to geophysics and meteorology network science measurements is shown in table 3. This complement of experiments is consistent with the requirements for network science established by the geophysics subgroup of the Mars Science Working Group (MSWG) on April 29-30, 1977. This subgroup categorized three classes of experiments for the Penetrator: Class 1 — Essential; Class 2 — Include if feasible; and Class 3 — Highly desirable. Class 1 experiments include seismometry, meteorology (pressure), magnetometry, and free and bound water analysis. Class 2 experiments include meteorology (humidity, temperature), heat flow, and α-p backscatter/X-ray fluorescence. Class 3 experiments include meteorology (wind speed and direction), ultraviolet photometry, and an imager. The list of experiments shown in table 3 includes all of the Classes 1 and 2 experiments.

TABLE 2.— PRELIMINARY PERFORMANCE OF POTENTIAL EXPERIMENTS

Experiment	Sensor	Measurement	Resolution	Range	Operation and Data Concept
Seismometer	Biaxial bubble tiltmeter	Horizontal motion	10^{-8} g	0.01-5 cps	Continuous; high clock speed when signal > noise, buffer stores 300 sec of data for successive major events.
	Force balance accelerometer (displacement)	Vertical motion	10^{-8} g	0.01-5 cps	Continuous; high clock speed when signal > noise, buffer stores 300 sec of data for successive major events
Magnetometer	Triaxial flux-gate	Internal and solar wind induced magnetic fields	0.05γ	$0\text{-}1{,}000\gamma$	Continuous; maximum data 1 measurement (mean) per second.
Heat flow	Thermocouple	Temperature profile along umbilical	0.05 K	170-230 K (1 m deep)	Intermittent; minimum 2 times per day
Stratigraphy	Accelerometer, longitudinal axis	Properties of layered deposits	Layered boundaries	0-10 m	Continuous during surface impact; 5-300 m/sec duration
Imager	Facsimile camera, array of silicon photodiodes	Image of scene optical extinction, sky particulates	0.1° IFOV	90°×360°	Intermittent; one portion of an image every day with one image compiled every few days.

TABLE 2.- CONTINUED

Experiment	Sensor	Measurement	Resolution	Range	Operation and Data Concept
Meteorology	Diaphragm, strain gage	Pressure	0.01 mb	3-12 mb	Intermittent; sensor on once per hour
	Thermocouple, thermister	Temperature	0.1 K	130-300 K	Intermittent: sensor on 10 min every 2 h, data: mean, skewness, standard dev.
	Hot wire, hot film, vane, ion beam deflection	Wind speed	0.5 m/sec	0-100 m/sec	Intermittent: sensor on 10 min every 2 h, data: mean, skewness, standard dev.
	Hot wire with thermocouples, ion beam deflection	Wind direction	10° azimuth	360°	Intermittent: sensor on 10 min every 2 h, data: mean, skewness, standard dev.
	P_2O_2 electrolytic, solid polymer electrolytic, dew point, Al_2O_3 film	Humidity	1 ppm	6-600 ppm (vol)	Intermittent: sensor on once per hour
	Photometer	Orientation, uv flux	1° azimuth and elevation	360°	Intermittent: sensor on 4 times per hour

TABLE 2.— CONCLUDED

Experiment	Sensor	Measurement	Resolution	Range	Operation and Data Concept
Geochemistry	Si detector-back scattered α particles and protons (^{242}Cm source)	Elemental composition	≈<1% concentration	C-Fe	Intermittent; several analyses over mission life, each analysis fixed time or fixed count. (PHA 512 ch/4,000 maximum counts/ch)
	*Ge detector-X-ray fluorescence (^{242}Cm, ^{109}Cd, ^{248}Am sources)	Elemental composition	≈ppth-ppm concentration Resol: Ge, ΔZ=1@Fe; proportional, and CdTe, ΔZ=3@Fe (FWHM)	K-U	
	CsI/PMT - γ-ray detector (natural, cosmic ray and RTA sources)	Radioactive elements, hydrogen, bulk density	≈ppm concentration ≈1% concentration 0.1 g/cm^3	H,K,Th,U + others	
	P_2O_5 electrolytic with oven (to 800° C)	Interstitial water, water of hydration, hydroxyl			Intermittent; one analyses over mission life, analysis concurrent with Δ1 of sample
	Drill	Soil acquisition		1-4 cm depth	Intermittent; several operations over mission life

*Requires Joule-Thompson cryostat to cool detector < 150 K, if Cd-Te is not available.

TABLE 3.— STRAWMAN PAYLOAD FOR PENETRATOR

I. Basic payload:

Experiment		Sensor (or measurement)	Location
Seismology	*	Biaxial bubble tiltmeter	Forebody
	*	Force balance accelerometer	Forebody
Magnetometry	*	Triaxial flux-gate	Afterbody
Meteorology	*	Pressure	Afterbody
	o	Temperature	Afterbody
	o	Humidity	Afterbody
Geochemistry	*	Water detection-free and bound	Forebody
	o	α-p backscatter/X-ray fluorscence	Forebody
	*	and drill, motor, sample holder	Forebody
Heatflow	o	Thermocouples	Umbical
Stratigraphy		Decelerometer	Forebody
Sun aspect		Photometer	Afterbody

II. Augmented payload:

Experiment		Sensor (or measurement)	Location
Meteorology	#	Wind speed and direction	Afterbody
	#	uv photometer	Afterbody
Imager	#	CCD camera	Afterbody

Categories established by Geophysics subgroup of MSWG:
*essential, o include if feasible, # highly desirable.

Only as feasibility studies progress on the less well-defined instrument concepts will it be possible to determine if any of the Class 3 experiments can be included on the Penetrator.

Because the geochemical experiments require a soil sample to be brought inside the Penetrator forebody, a drilling mechanism will be necessary. The idea currently conceived encompasses an integrated geochemical experiment package consisting of (a) drill mechanism and drive motor; (b) rotating soil sample holder; (c) water vapor detector, pump, and plumbing; (d) thermal chamber(s) with heater for either differential scanning calorimetry or differential thermal analysis; (e) radioactive source of α particles, protons and X-rays; (f) α-p backscatter detectors; and (g) X-ray detectors. The X-ray detector may require a cooling to $\sim$150 K. At this time it appears that sufficient volume and power is available for this experiment package.

Experiment Descriptions

The following section describes tentative details of the experiments listed in table 3. These descriptions include physical properties, instrument and functional descriptions, and operation plans. Data for these descriptions were obtained from potential experiment investigators whose names are given.

SEISMIC DETECTOR

TYPE: Bubble Tiltmeter and a Force Balance Accelerometer

EXPERIMENT INFORMATION SOURCE: Don Anderson, Wayne Miller — California Institute of Technology

PHYSICAL PROPERTIES:

Volume	400 cm^3
Weight	600 g
Power	90 mW

INSTRUMENT DESCRIPTION: The instrument is a single assembly containing the sensors, leveling motors, and electronics. The assembly is cylindrical in shape.

SENSOR ORIENTATION: The principal axis of the assembly is to be within 20° of vertical, the range of the leveling motors.

FUNCTIONAL DESCRIPTION: The seismic instrument is designed to measure motion in each of three axes. The sensor arrangement consists of a force balance accelerometer for measuring vertical motion and a bubble tiltmeter to measure horizontal motion. The force balance accelerometer utilizes a restoring magnetic force to position a suspended mass in a null position. The null position is maintained by position-sensing of the mass and applying restoring magnetic force (see fig. 4). The bubble tiltmeter is a spirit level, in which the position of the bubble is used to indicate the attitude of the fluid container with respect to gravity. The position of the bubble is sensed electrically.

INSTRUMENT OPERATION: Three axes of motion are sensed simultaneously. Each sample consists of three 11-bit words (10 bits plus sign). Samples are taken at the rate of 15 times/sec giving a measurement bandwidth of 5 Hz. Thirty seconds of data is stored in a continually updating buffer. The data in the buffer are examined both for amplitude and frequency content. If a seismic event is detected by the appropriate amplitude and frequency criteria, a time mark, accurate to 0.1 sec, and 300 sec of full rate sampling is stored for transmission. After an initial event, the buffered data are examined for another set of criteria which represents the seismic signals following an initial event. If this criteria is met, another time-marked 300-sec data set is stored. Up to three events may be transmitted per day. When no event occurs, averaged data are taken from the buffer and stored at the rate of a sample every 30 sec. Local vertical data are transmitted after bubble tiltmeter is centered.

DATA REQUIREMENTS: In the continuous mode, a 33-bit word is stored for transmission every 30 sec giving an average bit rate of 1.1 bits/sec. In the event mode up to three events, 300-sec duration at a sampling rate of 15 times/sec are stored for transmission. Up to a total of 1.4×10^6 bits are used in the event mode for an average bit rate of 16 bits/sec.

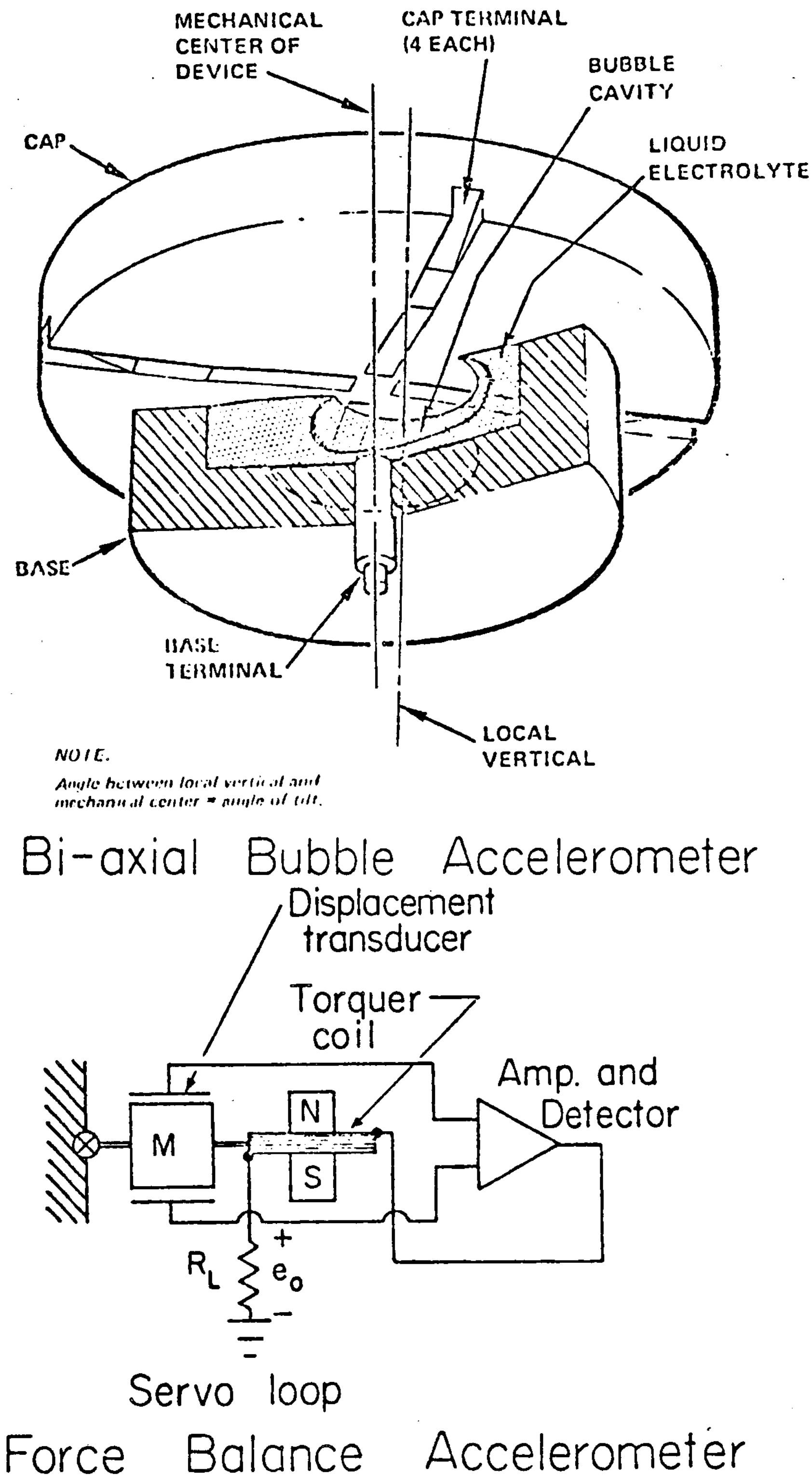


Figure 4.- Force balance accelerometer.

METEOROLOGY EXPERIMENT

TYPE: Four separate instruments to measure pressure, temperature wind velocity and direction, and humidity. Pressure is measured by diaphragm deformation indicated by a strain gauge bridge. Temperature is measured by a thermocouple. Wind direction and speed are measured by the ion flow technique. Humidity is measured by a P_2O_5 water sensor.

EXPERIMENT INFORMATION SOURCE: William J. Borucki — NASA Ames Research Center
James Tillman — University of Washington

PHYSICAL PROPERTIES:

Volume	300 cm^3
Weight	300 g
Power	75 mW

INSTRUMENT DESCRIPTION: The instrument is comprised of four sensor assemblies and an electronic assembly.

MOUNTING REQUIREMENTS: The experiment is mounted on the Penetrator afterbody such that the sensors are not obstructed and have free flow of the atmosphere about them. The temperature, wind velocity and direction sensor shall be within 20° of vertical for full measurement sensitivity and 1 m above Martian surface.

FUNCTIONAL DESCRIPTION: Pressure measurement is made by an absolute pressure gauge, which detects diaphragm distortion by means of a strain gauge bridge. Wind temperature is measured by a thermocouple. Wind velocity and direction are sensed by an ion flow technique. Humidity is measured by a P_2O_5 water sensor.

INSTRUMENT OPERATION: Pressure and humidity are measured continuously at the rate of once per hour. Wind speed, direction, and temperature are measured at preprogrammed rates on a 30-day cycle. Measurement period ranges from once per second to 64 sec per measurement.

DATA REQUIREMENTS: A continuous 2400 bits/day are used for pressure and humidity. Selected wind measurements give 4.6×10^5, 1.68×10^5, and 8.7×10^4 bits/day. The maximum average bit rate is 5.21 bits/sec. The minimum rate is 1 bit/sec.

MAGNETOMETRY EXPERIMENT

TYPE: Triaxial Fluxgate Magnetometer

EXPERIMENT INFORMATION SOURCE: Palmer Dyal, Ernest Iufer — NASA Ames Research Center

PHYSICAL PROPERTIES:

Volume	300 cm^3
Weight	400 g
Power	70 mW

INSTRUMENT DESCRIPTION: The instrument consists of two assemblies, the sensor assembly and the electronic assembly. Each assembly is packaged in a shape suitable to the dimensions of the volume available.

MOUNTING REQUIREMENTS: The sensor is located where stray fields due to magnetically permeable materials and power wires are minimized. Stray fields should not exceed 1γ.

FUNCTIONAL DESCRIPTION: The fluxgate magnetometer operates according to the following principles: The magnetic permeability of a ferromagnetic core is systematically altered by passing an alternating current through a coil wrapped around the core. The change in permeability causes the external magnetic field to oscillate. The oscillating field induces an electromotive force in a wire loop placed in the field. The induced electromotive force is proportional to the external magnetic field. The sensor assembly consists of two ring cores which are mounted orthogonally to one another. The core is driven to saturation by a drive winding wrapped toroidally around the core. Saturation is sensed by second toroidal winding, the drive control winding. At saturation, an imbalance in the circuit switches off the drive current, and the core relaxes to its initial state. Two sensor coils, wound diametrically around the core and orthogonally to each other, detect the change in the external magnetic field due to the change in the cores permeability. Taken together, the two sensors, each with two orthogonal sense windings, combine to provide sensitivity along three orthogonal axes, with a redundant measurement along one of the axes (see fig. 5).

DATA REQUIREMENTS: The three magnetic axes are sampled simultaneously. Each sample consists of three 10-bit representations of the magnetic field. An 8-bit range word is recorded every 6 min. The minium data rate is 9.3 bits/sec.

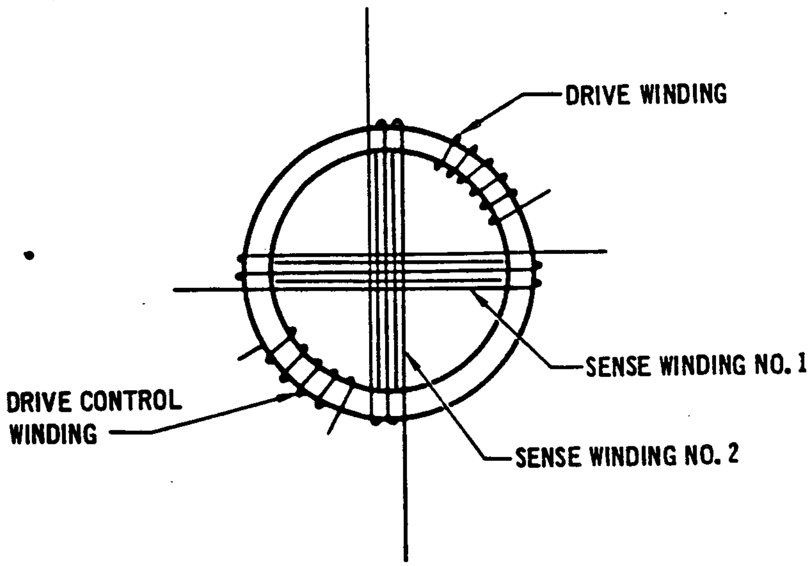


Figure 5.- Schematic representation of a magnetometer sensor.

ALPHA PARTICLE - PROTON BACKSCATTER AND X-RAY FLUORESCENCE

TYPE: Collimated beam of monoenergetic alpha particles are backscattered onto two silicon sensors. By logic techniques, alpha particles and protons are detected. Characteristic X-rays fluoresced in the soil sample are detected by a solid state X-ray detector.

EXPERIMENT INFORMATION SOURCE: Tom Economu, Anthony Turkovich University of Chicago

PHYSICAL PROPERTIES:

Volume	300 cm^3
Weight	400 g
Power	100 mW

INSTRUMENT DESCRIPTION: The instrument is comprised of three assemblies, the soil sampler assembly, the sample handling assembly, and the electronics and detector assembly.

MOUNTING REQUIREMENTS: Experiment is mounted as close as possible to the nose of the penetrator. Sample handling assembly shall be within 20° of vertical as gravity is used to move samples.

FUNCTIONAL DESCRIPTION: A collimated beam of monoenergetic alpha particles from radioactive curium (Cm^{242}) is used as a source. Particles backscattered from the sample target are detected by two annular-shaped semiconductor detectors. Amplified pulses from the detectors are compared and selected for alpha and proton particles, or fluoresced X-rays. The amplitude of the pulses are converted to a digital value. The values are used to cause accumulation in one of 512 channels. Total accumulation in any channel represents 4096 events (see fig. 6).

INSTRUMENT OPERATION: Analysis by the instrument are performed for a duration of one hour per day, or until one channel overflows. Either an alpha particle measurement, a proton measurement, or an X-ray measurement is made. For greater sensitivity, if power is available, a selected number (by command) of overflows may be used as criteria for measurement duration. The initial measurement made is an analysis of an alloy sample target which provides an instrument calibration. After the calibration, the soil sampler is activated to place a sample of soil on the target plate. Due to power limitations, the analysis of this sample begins the day following sample acquisition. A 1-h duration, or until channel overflows, completes the initial analysis of the particles. These data are evaluated and the experiment is commanded to complete either a fixed number of hours of analysis or commanded for a selected number of overflows. When the initial sample analysis is completed, the instrument changes mode and measures the alternate particles. The same experimental routine as before is accomplished. At the completion of the measurement (which may take up to a week) the soil sample is dropped from the target plate into a container for further analysis. On command, a new soil sample is obtained and the measurement sequence is repeated.

DATA REQUIREMENTS: The outputs of the semiconductor sensors are compared simultaneously to determine particle type. By command, either alpha, protons, or X-rays are accepted. The amplitude of the accepted pulse is accumulated. Count rates up to 10^4 counts/h are expected. At the conclusion of the measurement 6144 bits (512 channels by 4096 counts) are read from the channel accumulators to telemetry storage. A measurement consists of 512 12-bit words/d, which represents an average data rate of 0.07 bits/sec.

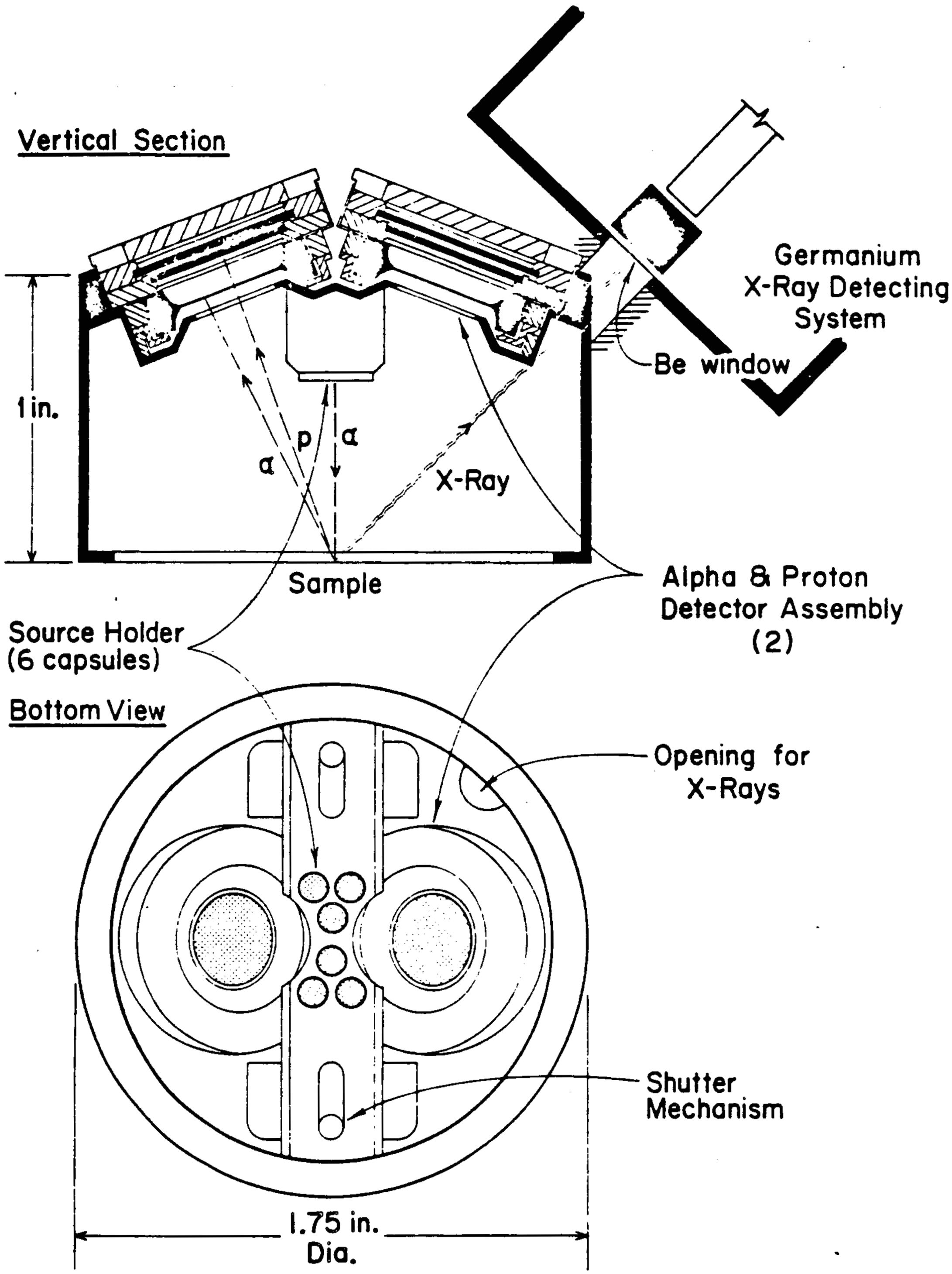


Figure 6.- "Mini-Alpha" — A combined (α, p, X-ray) alpha particle instrument.

HEAT FLOW

TYPE: The temperature history of the soil along the bore hole made by the penetrator (up to 10 m deep) is measured by a linear array of thermocouples.

EXPERIMENT INFORMATION SOURCE: Stephen Keihm and T. N. Canning, NASA Ames Research Center; Marc Langseth, Lamont Geological Obs., Columbia University

PHYSICAL PROPERTIES:

Volume	50 cm^3
Weight	70 g
Power	20 mW

INSTRUMENT DESCRIPTION: The instrument is comprised of 10 independently deployed thermocouples which are attached to the umbilical cable connecting the afterbody, at the surface, to the forebody of the penetrator. After impact the thermocouples remain suspended from the afterbody. The steel sheathed iron constantin thermocouples (0.010 in. diam) are of increasing metric lengths from 1 to 10 m long. An electronics assembly in the afterbody contains selection circuitry amplifiers and a reference for the thermocouples.

INSTRUMENT OPERATION: An absolute value of temperature is measured, as well as differential temperatures relative to the thermocouple at the 3-m depth. During the first day, the heat flow experiment is read out once per minute. On subsequent days the readout rate decreases until after a week the readout rate becomes once per hour. Data readout is accompanied by a time readout accurate to the nearest tenth of a second.

DATA REQUIREMENTS: A sample consists of an absolute reading of the 3-m sensor (10 bits), nine differential reading of 10 bits,and a 16-bit time word for a total of 116 bits per sample. The maximum data rate is an average of 2 bits/sec from the experiment.

WATER DETECTOR AND HYDRATED MINERAL ANALYZER

TYPE: Electrolytic cell containing P_2O_5 and heating chamber.

EXPERIMENT INFORMATION SOURCE: James Stephens — Jet Propulsion Laboratory; Duwayne Anderson — National Science Foundation

PHYSICAL PROPERTIES:

Volume	250 cm^3
Weight	150 g
Power	5 W for 1800 sec

INSTRUMENT DESCRIPTION: The instrument is associated with the soil sampler. A chamber beneath the alpha backscatter target plate receives the sample. The cell is juxtaposed by the chamber.

SENSOR ORIENTATION: No specific mounting requirements.

FUNCTIONAL DESCRIPTIONS: A sample, weighing 1 to 4 mg, is heated by a resistance heater. Temperature of the sample along with the change of resistance of the electrolytic cell indicate water content. Alternatively, a differential thermal measurement of the endothermic effect of water evolution may be used as the measurement technique (Dynamic Differential Calorimetry).

INSTRUMENT OPERATION: A null reading is taken from the cell indicating background water vapor. A sample is loaded into the chamber. Heating begins, the power input to the heater, temperature and cell resistance value are recorded for every 5°C increase in sample temperature. The upper temperature range for sample heating is 800°C. After reaching the upper temperature range the sample is allowed to cool and then transferred to a sample dump.

DATA REQUIREMENTS: A sample run consists of 100 power input, 100 temperature, and 100 cell readings of 10 bits each. Three thousand bits are used for each run.

ACCELEROMETER

TYPE: Piezoelectric transducer

EXPERIMENT INFORMATION SOURCE: Vern Oberbeck NASA Ames Research Center

PHYSICAL PROPERTIES:

Volume	30 cm^3
Weight	30 g
Power	30 mW

INSTRUMENT DESCRIPTION: The instrument is a single assembly containing the piezoelectric crystal.

SENSOR ORIENTATION: The sensitive axis of the crystal is parallel to the penetrator longitudinal axis.

FUNCTIONAL DESCRIPTION: The accelerometer will measure the deceleration produced while the penetrator is moving through Mars' soil.

INSTRUMENT OPERATION: The accelerometer generates a charge which is proportional to acceleration. The charge signal is sampled at a rate of 2×10^4 Hz and each sample is digitized to 10 bits. The sample rate will provide 100 samples during the shortest expected impact (5 msec) and 6000 samples during the longest impact (300 msec). The digitized samples will be stored in the memory. Since the duration of impact will be unknown, storage for the entire 6×10^4 bits will be reserved.

DATA REQUIREMENTS: The 6×10^4 bits of data are read out during the first day of the experiment.

SUN ASPECT AND PHOTOMETER

TYPE: Masked array of solar cells plus unmasked solar cell

EXPERIMENT INFORMATION SOURCE: T. N. Canning — NASA Ames Research Center

PHYSICAL PROPERTIES:

Volume	30 cm^3
Weight	20 g
Power	20 mW

INSTRUMENT DESCRIPTION: Instrument is comprised of two identical assemblies. Each assembly contains a masked array of solar cells and an unmasked cell.

MOUNTING REQUIREMENTS: Assemblies must be mounted on afterbody on opposite sides of the central structure where they will have the least obstructed view of the Sun.

FUNCTIONAL DESCRIPTIONS: Sunlight falls on one or both assemblies. The masked cells are connected together to measure the position of the Sun shadow. The unmasked cells are exposed to the Sun.

INSTRUMENT OPERATION: Once every 15 min, at preselected times, the cell outputs are read and digitized.

DATA REQUIREMENTS: Five solar cell readings of 10 bits each are transferred to telemetry storage every 15 min for an average bit rate of 0.06 bits/sec.

IMAGER

TYPE: Facsimile type camera using an optically filtered array of silicon photosensors.

EXPERIMENT INFORMATION SOURCE: Michael Malin Jet Propulsion Laboratory

PHYSICAL PROPERTIES:

Volume	170 cm^3
Weight	250 g
Power	900 mW

INSTRUMENT DESCRIPTION: The imager is a single assembly containing the sensors, positioning motors, and electronics. The assembly is cylindrical in shape.

SENSOR ORIENTATION: The principal axis of the assembly is to be within 20° of vertical.

FUNCTIONAL DESCRIPTION: The imager is a facsimile type camera which is designed to give accurate spectral representations of the surface of Mars. Impinging light on a set of silicon photosensors is filtered by narrow and wideband optical filters. Both color data and infrared spectral information are obtained from the sensors. Imaging is accomplished by a helical scan of the field. Horizontal lines extend for a full 360° while vertical range of scan is 90°. Image position referencing is taken from an initial mirror position and time of scan. Since the imager takes a full 360° × 90° picture continuously while operating, specific fields of view are taken by editing the data output. Various spectral outputs from the imager are taken by sampling the appropriate photosensors.

INSTRUMENT OPERATION: The 900 horizontal lines representing a field of view of 360° × 90° is divided into 0.1° increments resulting in 108,000 pixels. Pixels are encoded to a 12-bit word, six-bit range, and six-bit level giving a total of 1.29×10^6 bits per complete image, per color. A full color panorama requires three times 1.29×10^6 bits, or approximately 4×10^6 bits. Since this number of bits is beyond the capability of the Penetrator Memory System, portions of the image are taken daily until a full view is obtained. Images may be taken in one color per day or three colors up to a total storage requirement of 1.3×10^6 bits/d. Imaging on the surface may be done over a number of days. Imaging of the sky, however, is completed within a few minutes; however, the number of bits required for sky imaging is approximately 1 percent of surface images.

PENETRATOR SYSTEM DESIGN

General Description

The Penetrator system point design includes the Strawman Payload and four major assemblies. The major assemblies are the launch tube, the deployment motor, the two-stage aerodynamic decelerator, and the Penetrator. A mass statement is shown in table 4.

TABLE 4.- WEIGHT AND SIZES OF PENETRATOR SYSTEM ASSEMBLIES

Assemblies	Weight (kg)	Size	CG
Launch tube	7.5	29.2 cm diam × 234 cm long	
Retromotor	7.2		
Aero decelerator	16.5		
Penetrator with P/L	37.9	10.5 cm diam × 140 cm long	66.3 cm from nose
Total	69.1		
Contingency	6.0		
Allowable system weight	75.1 kg		

Launch tube— The launch tube shown in figure 7 houses the Penetrator holdback restrain mechanism, electrical umbilicals, and the deboost rocket motor assembly. The launch container consists of a glass fiber wrapped aluminum alloy tube. The container is hermetically sealed to ensure that any sterile deployment mechanisms which enter the Mars atmosphere will remain sterile. The hermetic seal is broken only when the end covers are opened immediately prior to Penetrator deboost. During the predeployment procedure, the covers are cut off from the container by flexible linear-shaped charges allowing the covers to swing open. Burnout of the rocket motor occurs before exit of the motor from the container.

Deployment motor— The TOW missile launch motor will be used as the design base for the deployment motor (ref. 6). The motor contains 1.91 kg of solid propellant. The relationship between the Penetrator mass and velocity, acceleration and travel before burnout are shown in figure 8. As can be seen for a 61.6-kg system, the propellant burnout occurs while the Penetrator is inside of the tube thereby minimizing the exhaust product contamination of the Orbiter. This also ensures that the motor force vector during burn is accurately aligned by the attitude of the Orbiter.

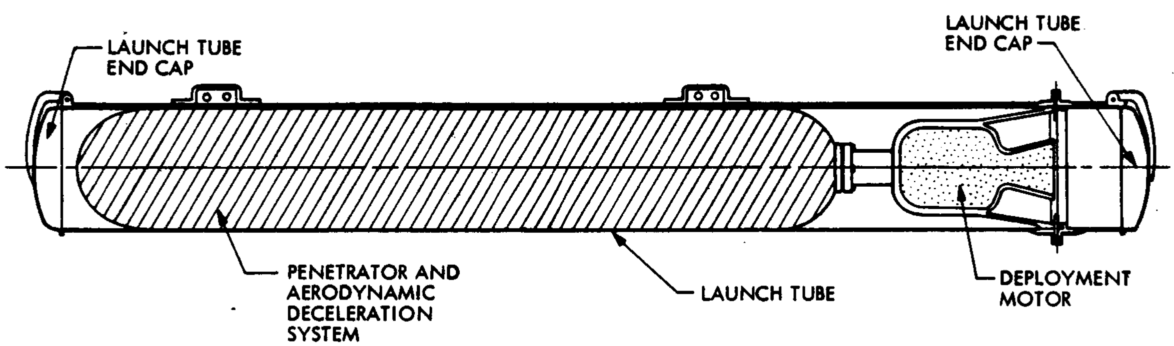


Figure 7.- Launch tube.

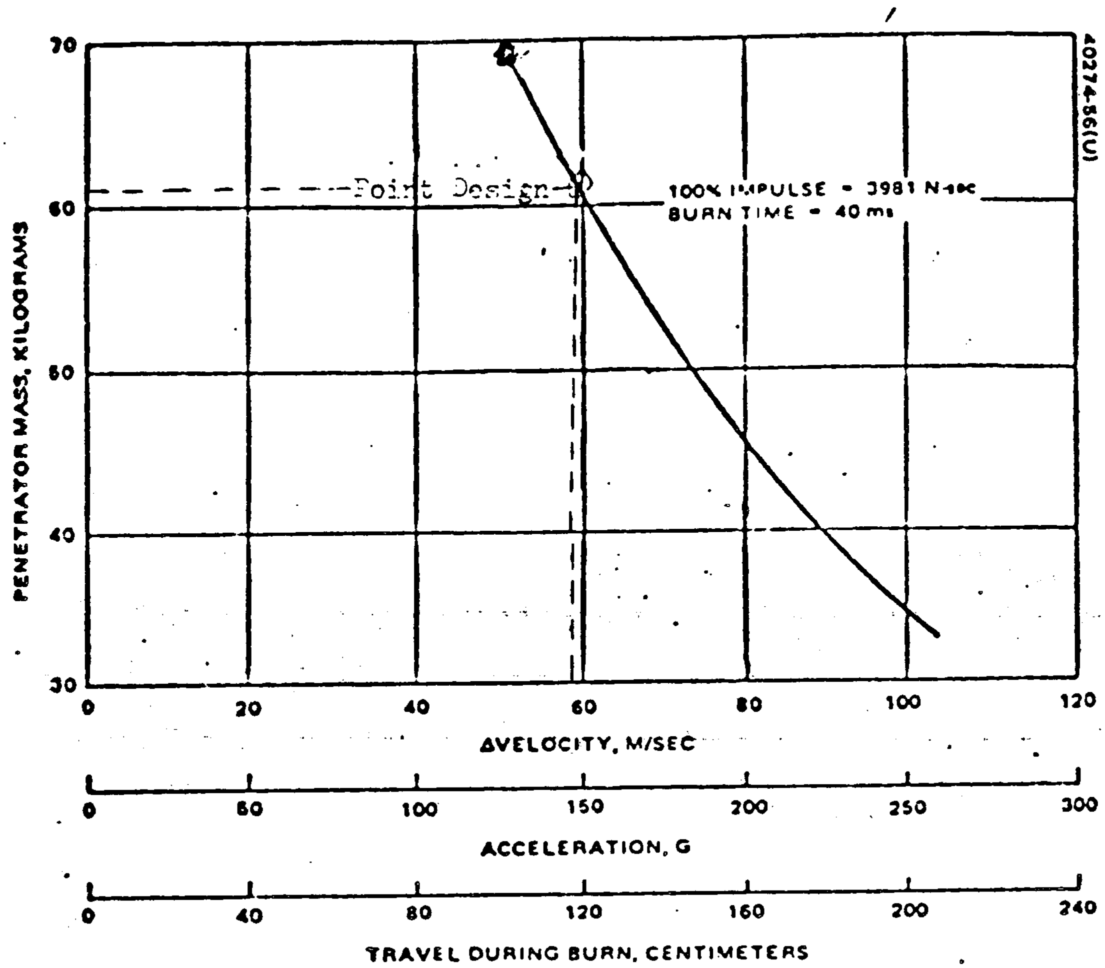


Figure 8.- Deployment motor performance.

Decelerators— The point design configuration includes two decelerator stages. The first stage of aerodynamic entry incorporates hypersonic deceleration and heating, and this aerodynamic stage must therefore be designed to withstand significant structural and thermal loads. The hypersonic decelerator is a large umbrella which unfolds after the Penetrator exits the launch tube. The apex of the umbrella covers the Penetrator nose and uses ablative material for heat protection. The ribs of the umbrella support a fabric skin which is coated with ablative materials.

The final stage must provide an aerodynamic profile compatible with maintaining satisfactory impact conditions over a range of altitudes. The tolerable impact conditions include impact velocities ranging from 135 m/sec to 165 m/sec and flight-path angles not to exceed 10°. The final stage deploys at about 13 km of altitude and 150 m/sec. The terminal deceleration is a small square drag plate of fabric supported by ribs which unfold from the Penetrator body. The decelerators have the following characteristics:

Hypersonic decelerator

Half-cone angle	60°
M/C_DA	0.034 slug/ft^2
Mass	15.8 kg
Material	Stainless steel, Kevlar, Polybenzimidazole, WCA graphite

Terminal decelerator

M/C_DA	0.16 slug/ft^2
Mass	9.7 kg

Total mass	16.5 kg

Penetrator— The basic design of the Penetrator is rocket shaped as indicated in figure 9. It has a blunted ogive nose and a conical flared aft section with a tapered sidewall thickness. The afterbody remains at the surface as the forebody penetrates the subsurface material. Since shock load is a function of penetration depth, the Penetrator forebody is designed to penetrate sufficiently deep in a broad range of surface materials. The parameters which influence penetration depth are weight/frontal area, terminal velocity, impact site material properties, and angle of attack. The following are the point design objectives for these parameters:

Weight to frontal area	=	7.1 psi
Terminal velocity	=	135 to 165 m/sec
Range of target materials	=	Sand to moderately porous basalt
Angle of attack	=	10° or less

Table 5 summarizes the characteristics of the Penetrator subsystem and payload. Mass, volume, and power requirements are delineated. In addition, the design base is shown.

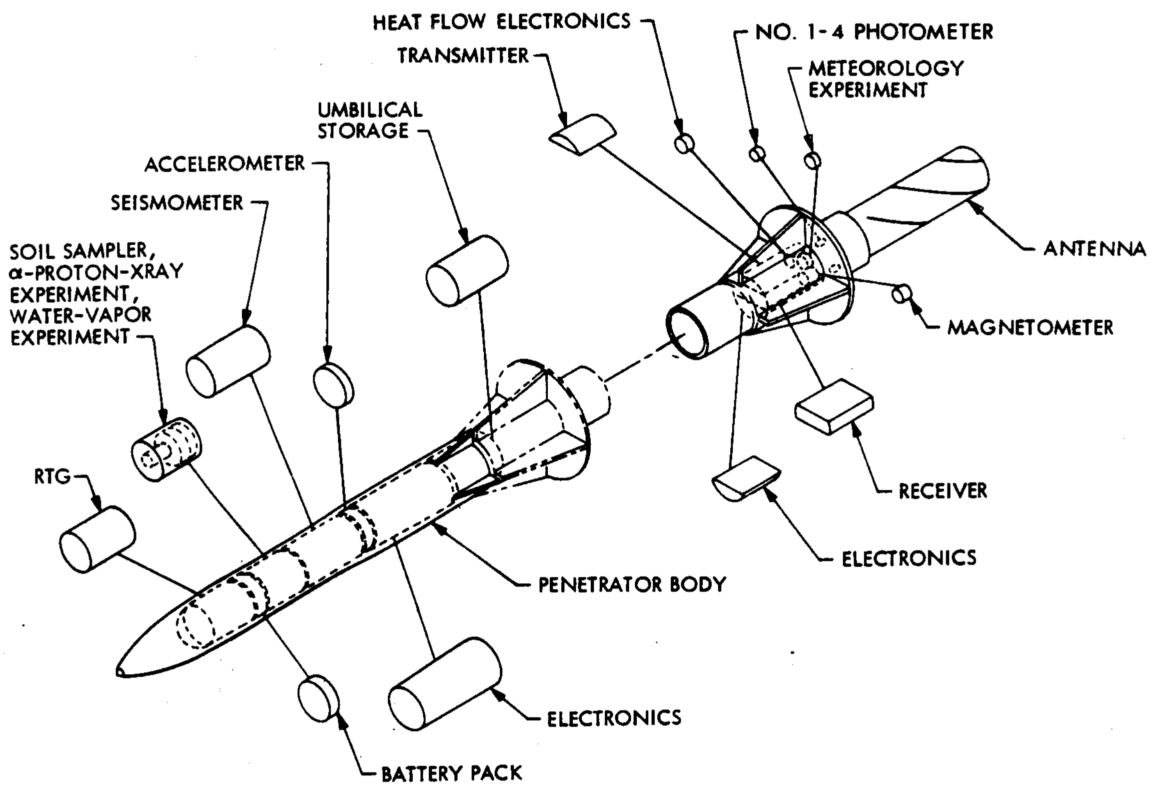


Figure 9.- Mars Penetrator.

TABLE 5.- SUMMARY OF PAYLOAD AND PENETRATOR CHARACTERISTICS

	Weight (g)	Volume (cm^3)	Power (mW) stby/peak	Design base
Strawman payload				
Seismometer	600	400	90/90	Aircraft sensors
Seismic leveler	--	--	0/3000	New
Heat flow	70	50	0/20	Thermocouple technology
α-proton X-ray	400	300	0/100	Viking proposal
Soil sampler	450	400	0/5000	New
Soil water	150	250	0/5000	New
Accelerometer	30	30	0/30	Existing design
Magnetometer	400	300	5/70	ARC design
Meteorology	300	300	75/75	Viking
Sun aspect	20	30	0/20	New
Penetrator subsystems				
RTG	420	200	--	ERDA developments
Battery	1560	480	--	Ni-Cad cell technology
Power control	340	200		New
Data process and memory	1280	1020	43/500	Existing chips, memory prototype
Umbilical cable	700	700	0	New
Transmitter	400	300	0/5000	Military programs
Receiver	480	360	0/200	Military programs
Antenna	500	500	0	Military programs
Heat pipe	300	430	0	New
Structure	29,500	--	0	New
Total	37,900	6250		

Spacecraft Interface

Preseparation— Prior to separation the Penetrator will be attached to the spacecraft via the launch tube. Power management will be supplied to the Penetrator from the spacecraft for housekeeping purposes and the spacecraft will relay engineering data to the Earth as part of its nominal data stream.

Mass. The total mass of the Penetrator system attached to the spacecraft is 75 kg, including contingency.

Electrical. Each Penetrator system will require two umbilical connectors with the Bus spacecraft. One connector will carry firing currents for the squibs used during separation. The other connector will carry command and telemetry circuits.

The firing currents required are:

Front cover explosive cord	2A
Aft cover explosive cord	2A
Motor igniter	3.4A

The command and telemetry circuits required are:

Command to Penetrator
Data from Penetrator
Experiment stimulus signal (approximately 5)

Thermal. Each Penetrator system will include an RTG which will produce a steady heat load. Heat will be rejected from the launch tube by radiation to space. The size of the RTG in each Penetrator system will be in the range of 10-20 W thermal.

Deployment Motor. The deployment motor will be designed to burn out before leaving the launch tube. Thus, all exhaust products will exit through the aft end of the launch tube.

When the deployment motor fires, the force transferred to the launch tube will be the sum of the forces which result from hot gas impingement on the tube wall, tube flare thrust, gas separation, and friction. The aft end of the tube will be designed to produce thrust to cancel all the other forces at a nominal design temperature. At off-nominal temperatures, dimensional changes of the launch tube will prevent perfect cancellation, as shown in figure 10.

Guidance and Navigation. The separation maneuver is divided into two parts: pointing by the Orbiter and propulsion by the Penetrator. The landing site error is determined primarily by the accuracy of the separation maneuver although aerodynamic errors, winds, and surface feature location also contribute to the landing site error. Of these, the effect of winds will be discussed as part of the Survivability section.

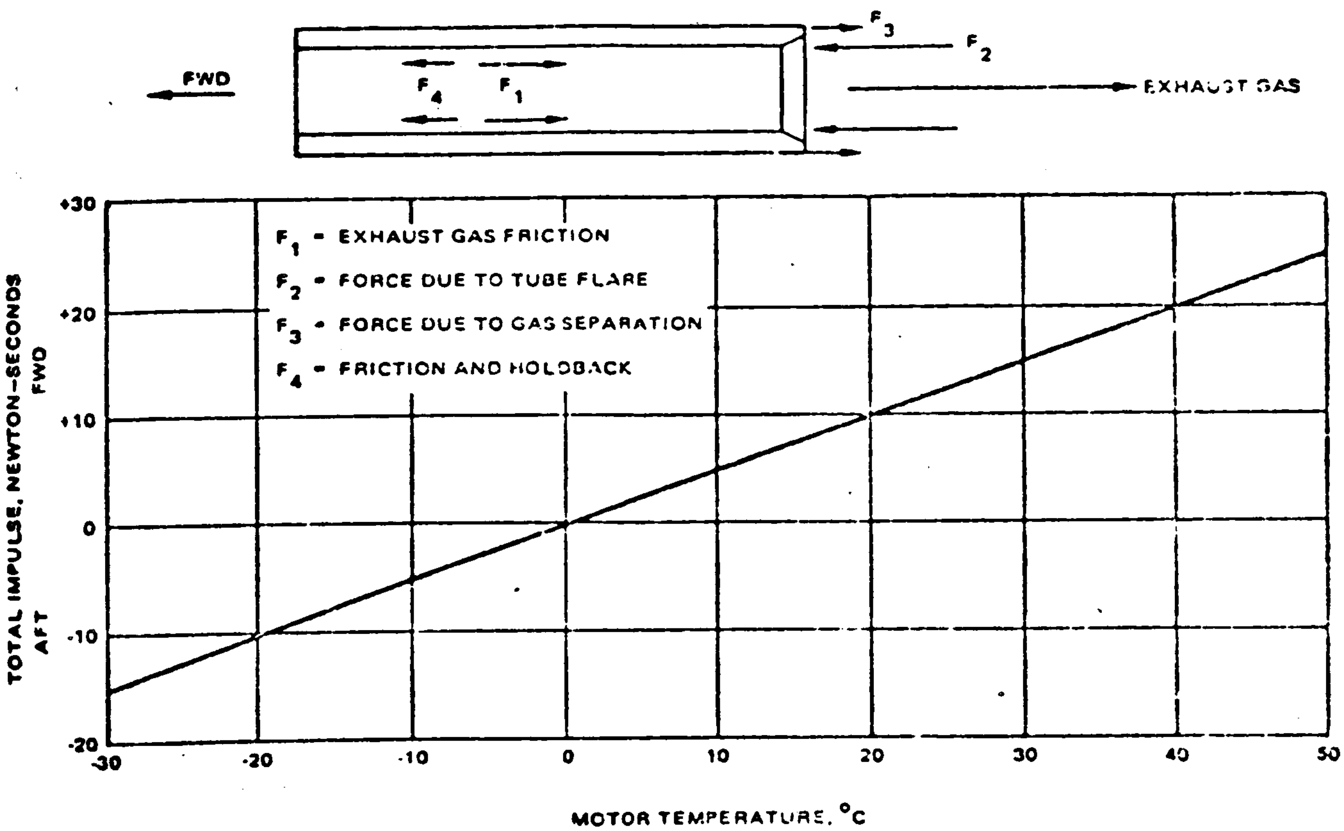


Figure 10.- Temperature effects on deboost motor performance.

The Orbiter contributes in two ways: knowledge of its position relative to the center of mass of Mars and the pointing of the launch tubes. Baseline optical navigation (taken until about 12 d before deployment) results in a position error (B-plane) of about 50 km (ref. 10). Obtaining optical navigation data until 1 d before deployment would reduce this error to about 10 km (the ephemeris error of Mars). Pointing of the Orbiter will, in general, require rotation about two axes. If in-flight calibration of the gyro scale factors occur, the pointing could be done to about 0.2° (3σ). Without in-flight calibration, this error could grow to 0.5°.

The solid propellant deployment motors burn to depletion of the propellant. Typical propellant loading and delivered impulse errors result in a total applied ΔV magnitude error of about 1.5 percent (3σ).

Combining all of these effects with an optimal targeting strategy results in a landing site footprint of about 100-km downrange by 80-km crossrange.

Postseparation— After separation, the only interface will be a relay link to and from the Penetrator. Commands from the Orbiter will be used to change Penetrator operating modes, turn experiments on and off, and readout the Penetrator memory to the Orbiter. The Penetrator-to-Orbiter communication link has the following performance features assuming a 400-MHz carrier and a 500-km Mars circular orbit with a minimum pass time of ten min.

1 W Penetrator transmitter RF power
2500 BPS transmission bit rate
800 BPS command bit rate
1.5 million bits per Penetrator pass

The baseline telemetry link for Penetrator data has a single receiver in the polar Orbiter. An identical receiver in the low-inclination Orbiter is for the Rover deployed science package and to backup the Penetrators. Thus, redundancy exists only for those Penetrators at latitudes between about ±45°. The addition of a minimum of one more receiver would alleviate this failure mode and add the capability to receive data from 2 Penetrators simultaneously. This mode is discussed further in the section on *Multiple channel*.

Penetrator Subsystems

Structure— The structure of the Mars Penetrator which meets the general requirements to impact at velocities of 135 to 165 m/sec, to withstand impact loads of 1800 to 2000 Earth g's, and to penetrate a wide range of soil densities from 1 to 15 m is presented in figure 11. This design concept features an outer casing of HY 180 steel used to fabricate the forebody. The afterbody is made from 7075-T7351 aluminum. The science experiments assembly structure is machined from 7075-T7351 aluminum. A tangent ogive nose with a length-to-diameter ratio of 2.4 was chosen because of proven performance characteristics. The length and diameter of the Penetrator were chosen to provide stability and bending resistance during penetration. The diameter is a constant 9 cm to sta. 50. The diameter increases as a cone to

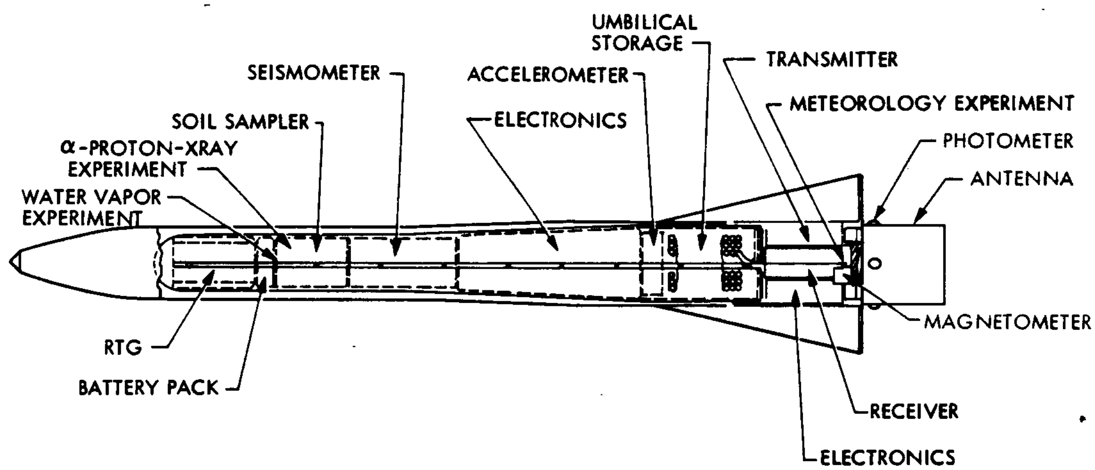


Figure 11.- Penetrator assembly.

10-1/2 diam, at sta. 71, which is maintained for the rest of the 140-cm length. This concept has a weight-to-cross sectional area ratio $(W/A)_{CS}$ = 23.6 psi for the thick wall section and 29.0 psi for the thin wall section and L/D of 13.3. These L/D and $(W/A)_{CS}$ ratios compare favorably to designs of the Clustered Airfield Defeat Munition (CADM) tested by LMSC. In these tests the Penetrators survived penetration of 12 in. of reinforced concrete at angles of attack (α) of 3° coupled with an obliquity angle θ of 45°, and $\alpha = 10°$ with $\theta = 0$. The penetration $(W/A)p$ relationships for the Mars Penetrator and CADM submunition are 7.1 and 5.2 psi, respectively. The Mars point design provides an internal volume of 6900 cm^3.

Installation of the science experiments is accomplished by the use of a clamshell-like subassembly which houses the individual experiments, electronics, and provides a cable trough with bulkheads for connecting multipin connectors from each experiment to the electronics or power supply. In addition, the umbilical, umbilical pay-out reel and umbilical mounted heat flow sensors are installed in the science assembly structure.

The science assembly structure is match fit to the inside diameter of the Penetrator case and is hard mounted at final assembly, thereby giving additional stiffness to the Penetrator. Of note is the window which is provided through the case and science assembly structure allowing deployment of the soil sampler auger.

The windows are accurately aligned at preassembly along with the load carrying shear pins. The afterbody is pressed into the forebody to eliminate the chance for rubble to enter and jam the separation joint during penetration of the surface crust.

The final assembly sequence will be: (1) assembly of experiments to the science assembly structure as shown in figure 11; (2) assembly of experiments and antenna to the afterbody; (3) assembly of the science assembly structure to the forebody; and finally, (4) assembly of the afterbody assembly to the forebody assembly.

Data processing and control— The data processing and control for the Penetrator is done with a microcomputer. The functions of experiment sequencing, power conditioning and control, commands, and timekeeping are performed in addition to the usual functions of data collection, temporary storage, and formatting (ref. 44). The multiplicity of functions performed are mostly under software control to minimize size and power consumption. Since the subsystem relies heavily on the microcomputer program, it is necessary to minimize the time spent on data handling and processing so that other system functions may be performed. This is achieved by having the equivalent of a tape recorder, a Bubble Memory, which can accept data at any time necessary. Thus, the microcomputer is relieved of memory management functions and large temporary storage capability. The Bubble Memory, which is arranged as a long shift register, accepts formatted and serialized data in the exact form needed for transmission. When data is sent to the Orbiter, the Bubble Memory transfers bits to the transmitter at approximately one hundred times the data loading rate. A conceptual block diagram of the data handling system, experiment electronics, and communications subsystem is shown in figure 12.

Microcomputer. The microcomputer is a low power set of Complementary Metal Oxide Semiconductor (CMOS) integrated circuits. A 12-bit microprocessor chip has been selected for greatest compatibility with the science data requirements. A twelve thousand word Read Only Memory (ROM) is used to store the programs for experiment and system operation. Temporary storage for the microcomputer is accomplished with eight thousand words of Random Access Memory (RAM). There are five input/output ports on the subsystem which communicate with the experiments, the system, and the Bubble Memory.

A preliminary design shows that the microprocessor can be implemented with approximately 80 integrated circuit chips. To meet the volume constraints of the Penetrator these circuits are packaged in high density hybrid arrays.

The tentative specifications for the microcomputer are:

Processor system

Data word size	12 bits
Program memory	12 K words
Random access memory	8 K words

Input/Output

Analog channels (up to 64 channels, ±2048 counts)

Data input (IN)	12 bits
Multiplex control (OUT)	6 bits
A/D encode (OUT)	Pulse
A/D complete (IN)	Pulse

Digital channel (512 channels, 4096 count)

Data input (IN)	12 bits
Channel address (OUT)	10 bits
Channel execute (OUT)	Pulse
Ready (IN)	Pulse

Power control

Control state (OUT)	12 bits

Experiment control (OUT)	12 bits

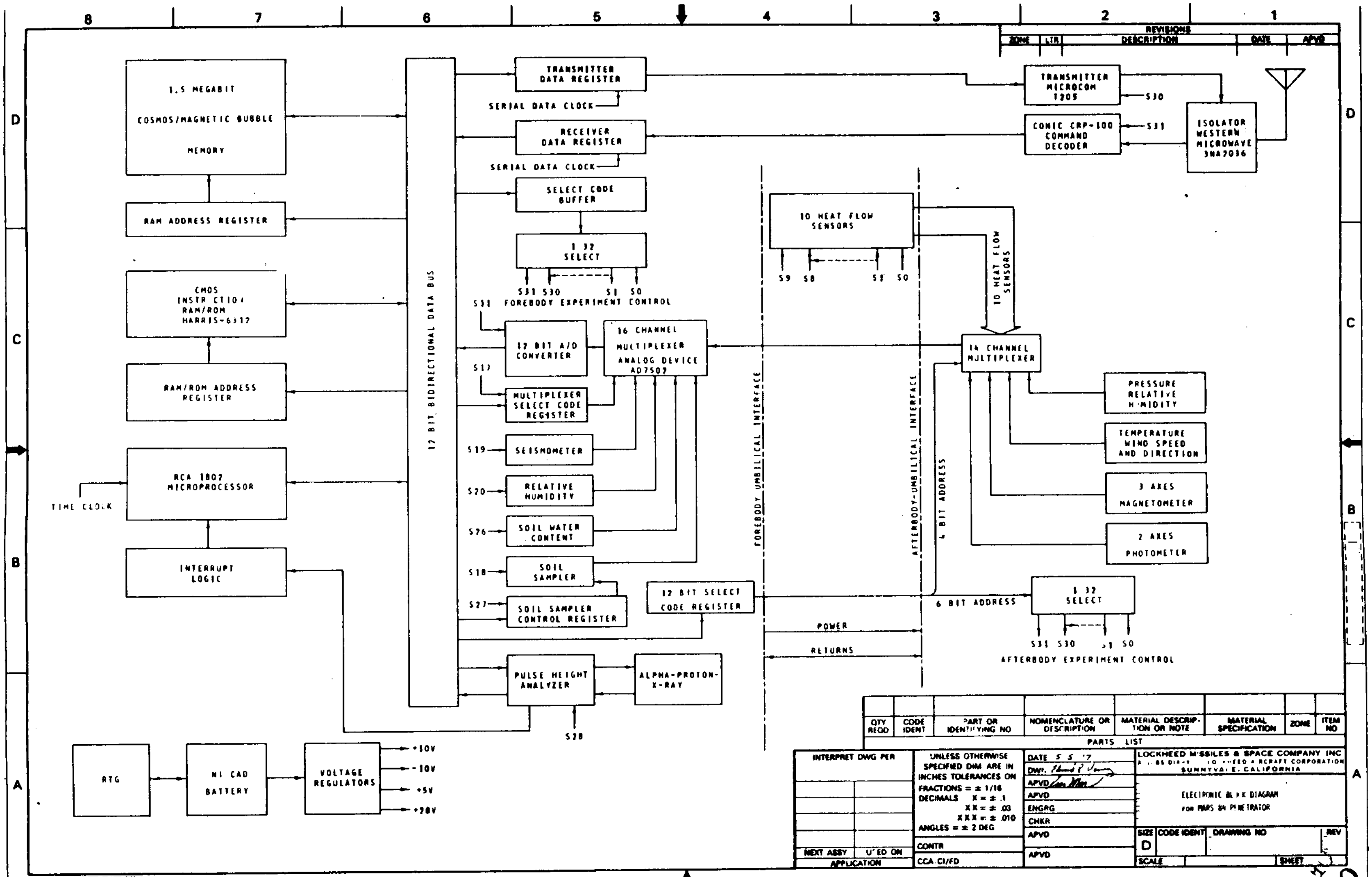


Figure 12.— Electronic block diagram.

Serial memory

Data out (OUT)	12 bits
Load (OUT)	Pulse
Reset (OUT)	Pulse
Transfer complete (IN)	Pulse

Physical characteristics

Volume	475 cm^3
Power	43 mW

Memory Assembly. The basic element of the Memory Assembly is a Magnetic Bubble Memory (MBM). The MBM stores bits as cylindrical domains (bubbles) in a thin magnetic substrate. The bubbles have opposite polarization to that of the substrate. Permalloy patterns on the substrate, when magnetized by a rotating in-plane magnetic field, cause the bubble to move from one pattern to the next. Magneto-resistive sensors at one end of the permalloy pattern detect the presence of the bubble. Bubbles are created by a current carrying hairpin loop. Typical bubble dimensions are from 2 to 5 μm. The small size of the bubbles allows chips to be built containing up to 250,000 bits. High density memories are made by placing a number of chips in a package. Power can be turned off with no loss of data from the MBM. This feature allows the MBM to be operated in a duty cycle mode, reducing the power consumption.

The storage capacity for the Memory Assembly for the Penetrator is 1.5 megabits. This capacity represents a continuous 18 bits/sec from the Penetrator experiments for each Martian day. The Memory Assembly consists of the MBM, driving circuitry, an input serializer, and an output serializer. The serializers are needed to read in and read out bits at the preferred rate (50 kHz) of the MBM.

Though the Memory Assembly requires 5 W when operating, the low-bit rates used on the Penetrator give an equivalent continuous power use of 10 mW.

Tentative Memory Assembly Specifications:

Performance

Total storage capability	1.5×10^6 bits
Input data	12 bit parallel
Input data rate	Asynchronous up to 50 words/sec
Output data	Bit serial
Output data rate	Asynchronous up to 10 K bits/sec

Physical characteristics

Volume	350 cm^3
Power	
Operating	5 W
Standby	0 W
Average	7.5 mW

Communications— This subsystem includes the antenna, transmitter, and receiver, all of which are mounted on the Penetrator afterbody. The telemetry and command frequencies are both nominally set at 400 MHz since simultaneous transmission and reception are not planned. Tables 6 and 7 are the design control link margins for the 500 km circular, relay orbit. All entries in these tables are for worst case conditions. Figure 13 shows the relay link geometry for acquisition 20° above the horizon.

The antenna is a quadrifilar helix with 3/4 wavelength elements wrapped for 3/4 turn. This antenna is shown in figure 14 and its radiation pattern in figure 15. The antenna is encased in a storage container until after impact and then is deployed. The deployment mechanism is a spring which is released by an explosive latch.

As indicated in the design control tables, the telemetry rate is 2500 bps and the command rate is 800 bps. The required minimum signal-to-noise ratios (E/No) in the tables reflects a conservative assumption of uncoded coherent FSK modulation. A full design study would, in all likelihood, result in a more efficient modulation with coding and an associated increase in the link margin.

The penetrator transmitter and receiver are both crystal controlled for frequency stability. This is necessary to provide efficient modulation and rapid signal acquisition. Furthermore, for the telemetry link crystals provide the necessary short term stability for Doppler measurements, which are necessary to accurately locate the penetrators. The transmitter is based on units developed for military penetrator programs.

Power— The Penetrator power profile consists of three parts: (1) a steady low-level power requirement to operate the experiments during most of a solar day; (2) a high-power level to operate the transmitter and receiver during the short communication periods; and (3) a high-power level necessary for the first few months to operate the geochemical experiments and soil sampler. The power supply which has been selected consists of a set of two secondary Ni-Cad batteries to provide the power for the transmitter, a Radioisotope Thermoelectric Generator (RTG) to provide low-level power and recharge the secondary batteries, and a set of four primary Ni-Cad batteries to provide the short-term high power.

The Ni-Cad battery was selected due to its proven long cycle life. Two batteries, each of 5-W-h capacity (9 button cells), were selected for the secondary set in order to achieve a discharge depth sufficient to assure efficient operation. Four similar batteries are used for the primary source for commonality but are not recharged.

An RTG was selected as the power source due to its high reliability, constancy of output over mission life, and insensitivity to location and orientation of the Penetrator, and heat generation. The heat is needed to maintain an acceptable battery temperature. The RTG fuel is plutonium oxide. The best thermoelectric material appears to be silicon-germanium (SiGe). An SiGe RTG has been shocktested successfully to the levels required for the Mars

TABLE 6.- PENETRATOR TO ORBITER TELEMETRY

Design control table:	
Frequency	400 MHz
Total transmitter power 1 W	30 dBm
Transmitter circuit loss (assumed)	-2 dB
Transmitter antenna gain (On-axis)	0 dB
Transmitter antenna pointing loss (70%)	0 dB
Range	1873 km
Space loss	-145 dB
Tropospheric/Ionospheric losses (theoretical)	-0.5 dB
Receiving antenna gain (On-axis)	4 dB
Receiving antenna pointing loss (55°)	-2 dB
Polarization loss (circular to circular)	-0.5 dB
Multipath allowance	-5 dB
Receiving circuit loss (assumed)	-1 dB
Total received power (subtotal)	-122 dBm
Receiver noise spectral density (725 K)	-170 dBm/Hz
Received power/noise spectral density	48 dB
Data rate 2500 bits/sec	34 dB
Receiver loss (assumed) (demodulation)	-1 dB
Required E/No (10^{-3} error rate, coh. FSK)	9.6 dB
Threshold power/noise spectral density	44.6
Total margin	3.4 dB

TABLE 7.- ORBITER TO PENETRATOR COMMAND

Design control table:	
Frequency	400 MHz
Total transmitter power 1 W	30 dBm
Transmitter circuit loss (assumed)	-1 dB
Transmitter antenna gain (On-axis)	4 dB
Transmitter antenna pointing loss (55°)	-2 dB
Range	1873 km
Space loss	-145 dB
Tropospheric/Ionospheric losses (theoretical)	-0.5 dB
Receiving antenna gain (On-axis)	0 dB
Receiving antenna pointing loss (70°)	0 dB
Polarization loss (circular to circular)	-0.5 dB
Multipath allowance	-5 dB
Receiving circuit loss (assumed)	-2 dB
Total received power (subtotal)	-122 dBm
Receiver noise spectral density (1064 K)	-168.3 dBm/Hz
Received power/noise spectral density	46.3 dB
Data rate 800 bits/sec	29 dB
Receiver loss (assumed)	1 dB
Required E/No (10^{-4} error rate, coh. FSK)	11.4 dB
Threshold power/noise spectral density	41.4
Total margin	4.9 dB

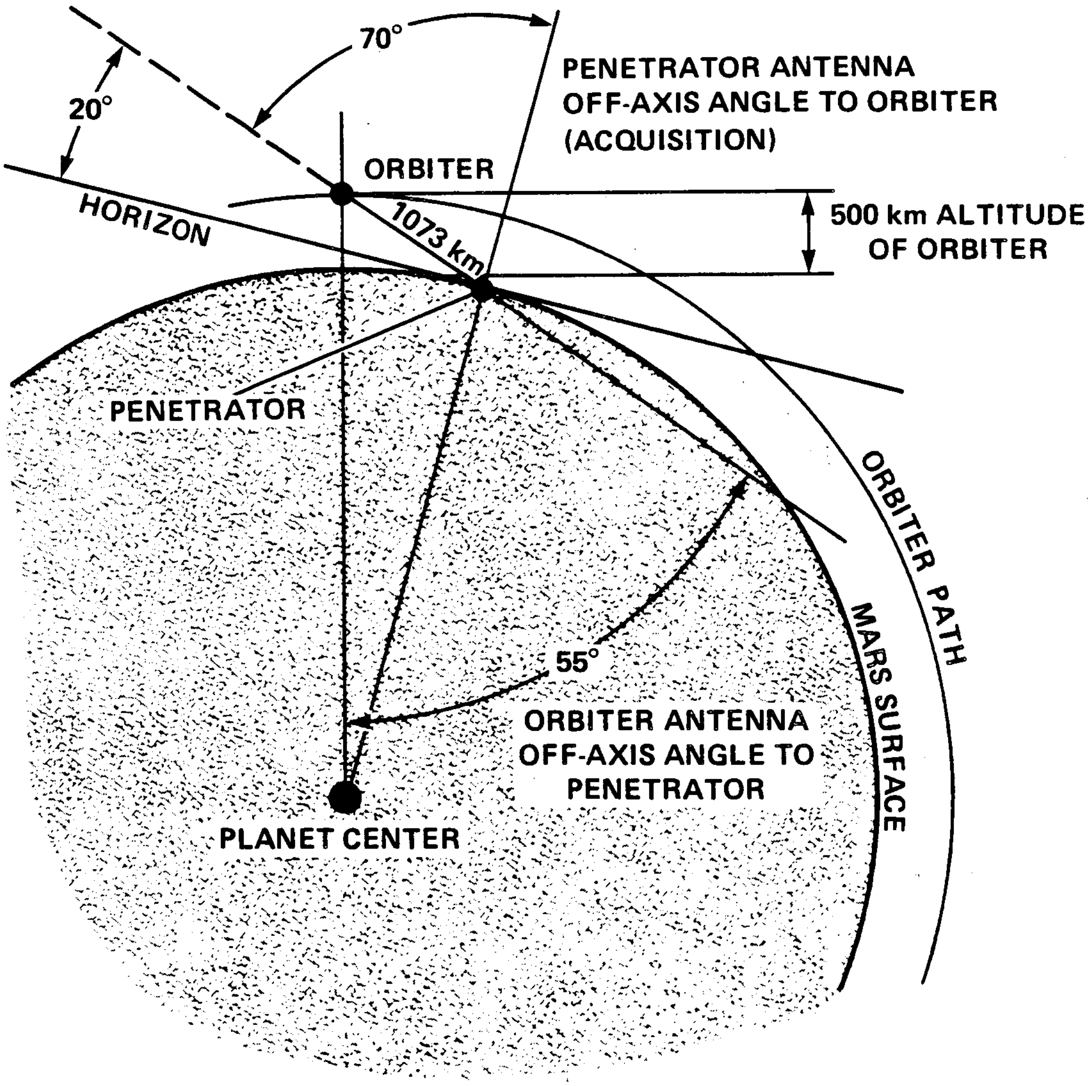


Figure 13.- Communications geometry.

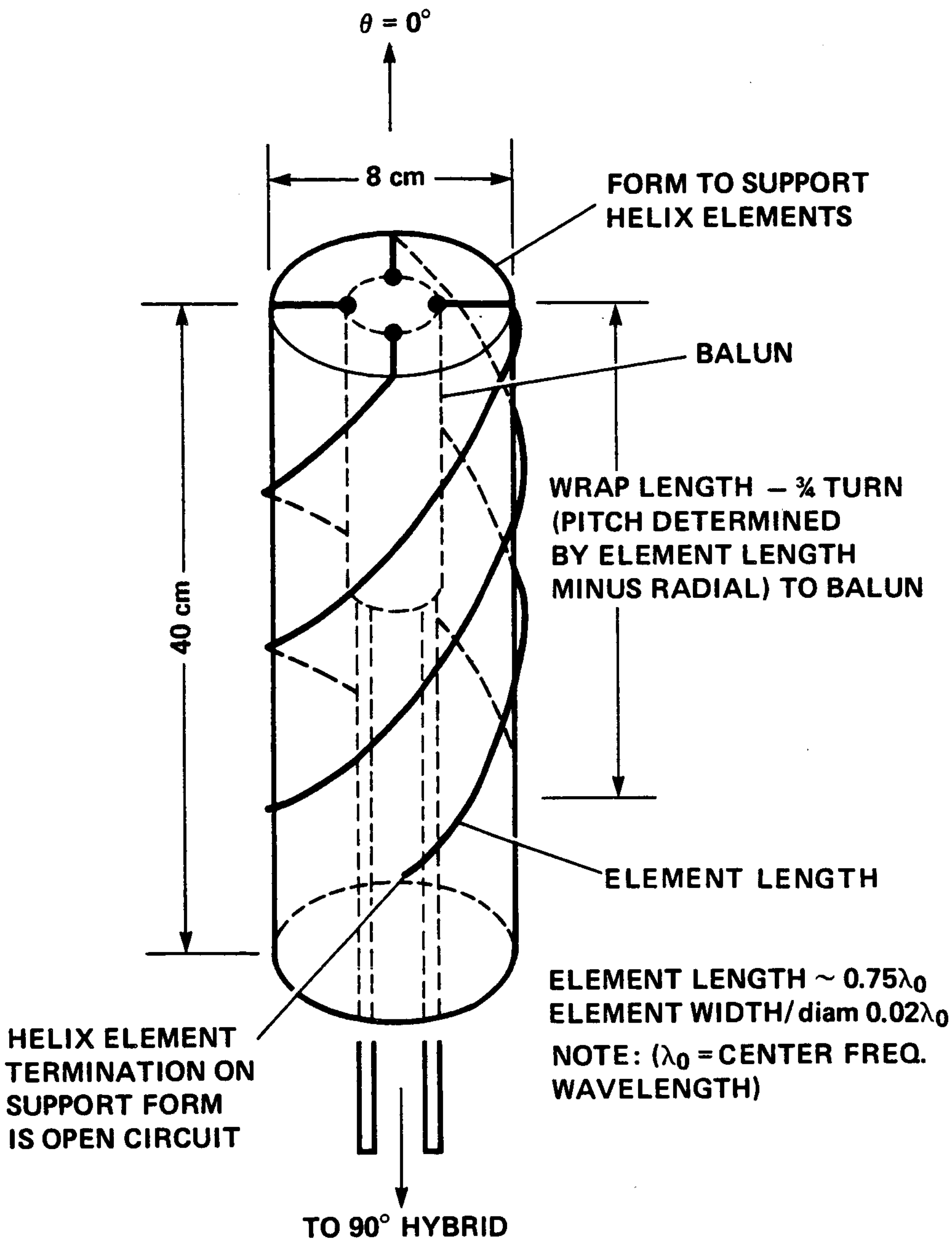


Figure 14.– Quadrifilar heliax antenna configuration.

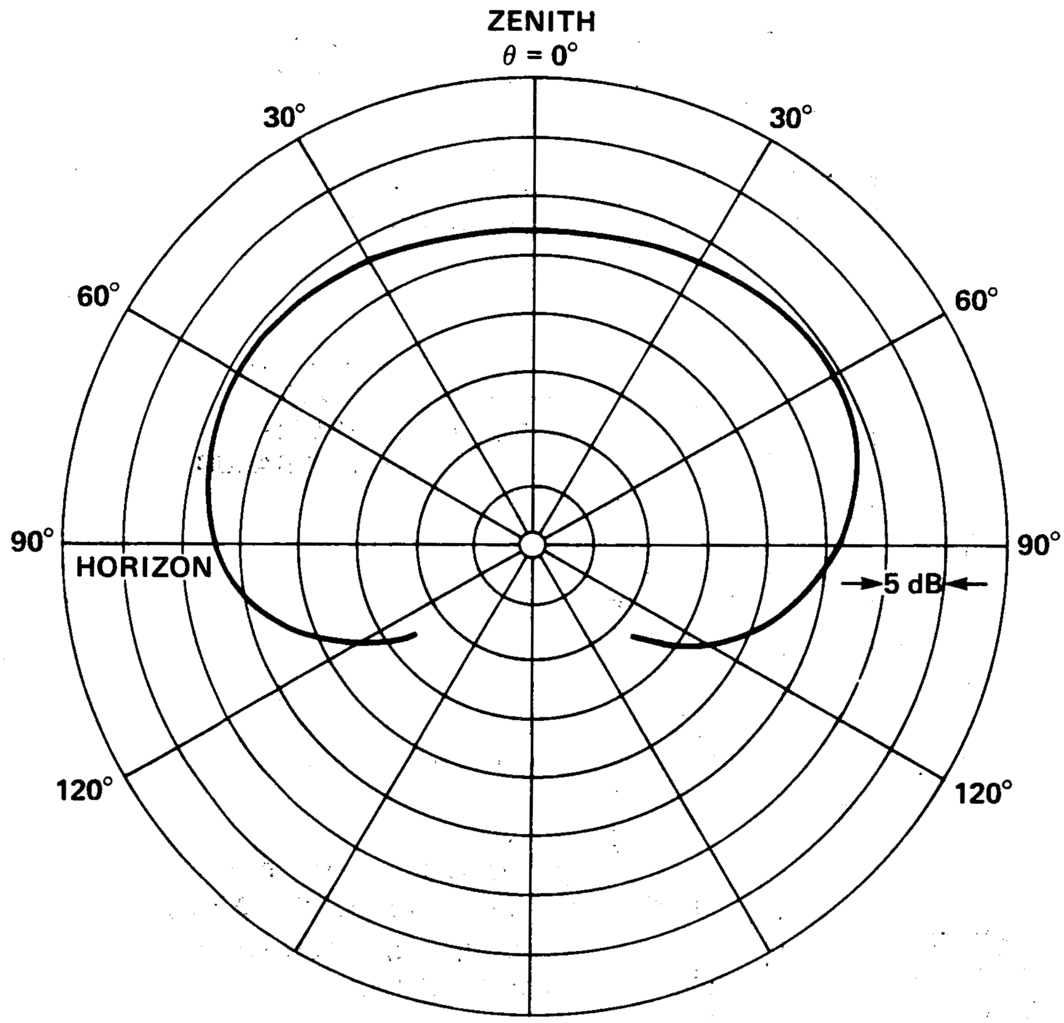


Figure 15.— Quadrifilar heliax antenna radiation pattern.

Penetrator mission. The RTG provides an output of 480 mW at the end of life.

A conceptual block diagram of the power subsystem is shown in figure 16 and a power budget in table 8.

TABLE 8.- POWER BUDGET FOR PENETRATOR

		Power, mW	W-H/Sol
RTG power output @ 4% efficiency		480	
Inverter efficiency @ 90%		-43	
Battery charge efficiency @ 60%		-174	
Power for all systems		262	6.46
Penetrator systems			
Transmitter	5 W for 600 sec	-33 av.	0.814
Receiver	0.2 W @ 10% duty cycle	-20 av.	.493
Microcomputer	0.048 continuous	-48	1.184
Power for experiments		161	3.969
Penetrator continuous experiments			
Seismometer		-90.0	2.219
Meteorology	75 mW @ 50%	-37.5	.925
Magnetometer	70 mW @ 10%	-7.0	.173
Solar photometer	30 mW @ 0.6%	- .2	.005
Heat flow	30 mW @ 3%	- .9	.022
Net power gain per sol		25.4	0.625
Primary battery			20.0 W-H
Seismic leveler	(3 W for 600 sec) 4 times		-2.0
Soil sampler	(5 W for 600 sec) 10 times		-8.3
Pulse height analyzer	(0.07 W for 1 h) 30 times		-2.1
Alpha proton backscatter	(0.1 W for 1 h) 30 times		-3.0
X-ray	(0.1 W for 1 h) 6 times		-0.6
Water detector	(5 W for 0.5 h) 1 time		-2.5
Primary cell reserve			1.5 W-H

Thermal control— The most severe requirement on the thermal control subsystem is to maintain the Nickel-Cadmium battery within an acceptable operating temperature range (255 to 325 K). All experiments and electronics will operate comfortably within this range and, in fact, can tolerate even lower temperatures.

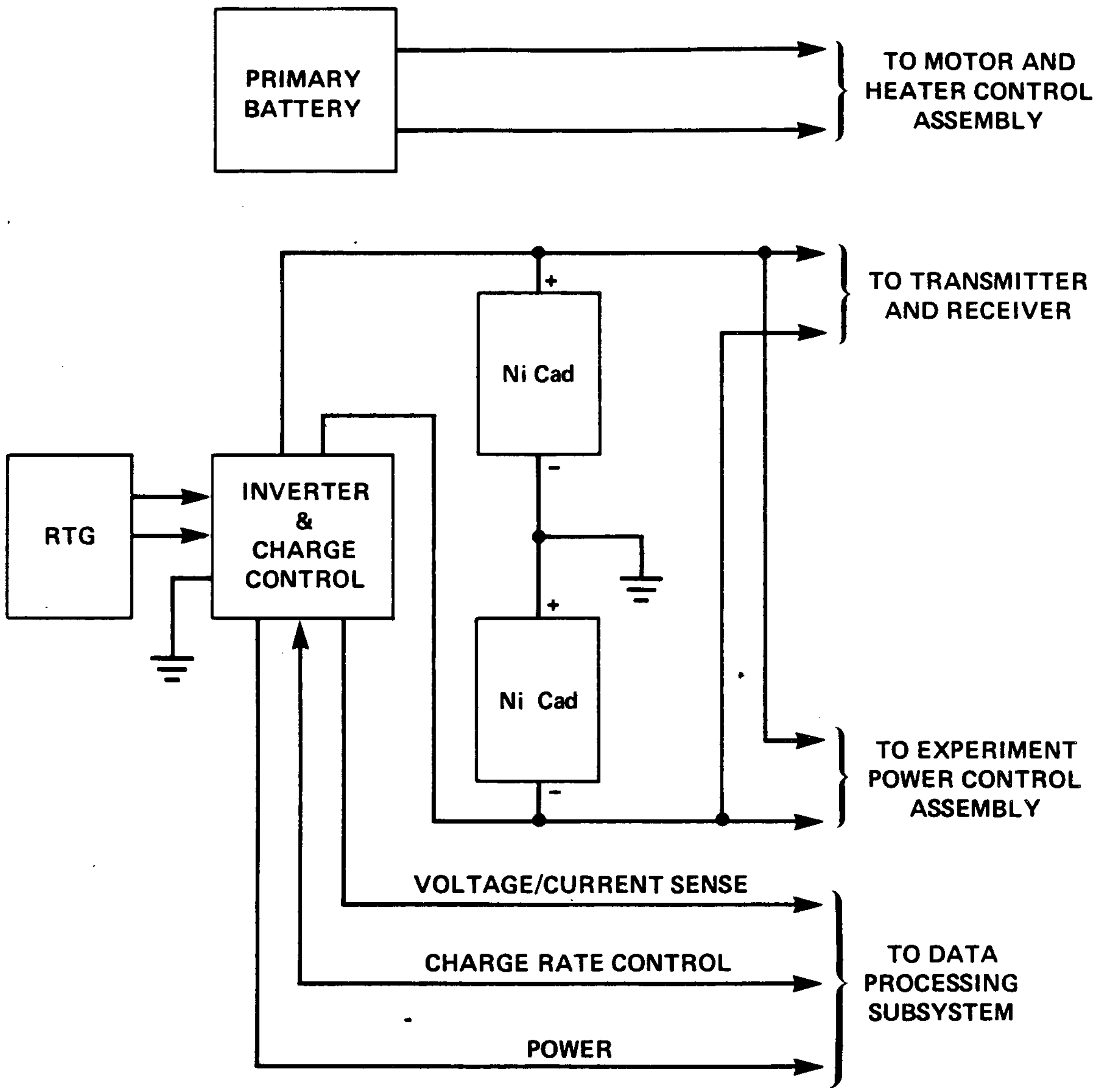


Figure 16.- Penetrator power subsystem conceptual block diagram.

After penetration, the Penetrator forebody will be buried beneath the surface and will be in intimate contact with the surrounding soil. Since diurnal and seasonal temperature changes do not extend deeper than about a meter, the soil temperature around the Penetrator will depend primarily on latitude and will range from 225 K at the equator to 155 K at the poles.

The thermal control system will consist of the RTG heat source, insulation between the battery and the Penetrator skin, and a variable conductance heat pipe to control heat conduction into the soil.

The RTG and battery will be mounted at the forward end of the Penetrator with the heat pipe "evaporator" connected to the battery. The heat pipe will carry excess heat to its "condenser" which will be connected to the back end of the Penetrator skin. The heat pipe will use a working fluid such as methanol and a control gas such as helium to vary conductance with temperature.

A typical history of battery temperature is shown in figure 17.

Umbilical cord— The point design umbilical cord consists of 20 copper wires of 30 gauge. Four will be power lines and three power return. The wires will be wound on a cone to facilitate unreeling under high acceleration conditions. Unreeling tests are presently being run at NASA Ames on the laboratory setup shown in figure 18.

Soil sampler— The soil sample collector consists of a deeply fluted drill which rotates inside a nonrotating sleeve. The drill bit is tipped with a hard material such as Tungsten carbide selected so as to avoid contamination of the sample with elements of interest. The drill and sleeve are advanced at slow speed to minimize the power required and to avoid thermal alteration of the sample. The low speed also reduces the likelihood of drill seizure.

The first part of the drill cuttings will be highly contaminated with material abraded from the Penetrator shell and altered by diffusion resulting from the severe heating during impact. Therefore, the nonrotating sleeve will deposit the first cuttings in a waste chamber. As the drilling proceeds beyond about 2 cm, the inboard end of the sleeve will advance to a chute leading to the sample tray of the α-proton X-ray instrument. Following this, continued drilling will advance the sleeve over the chute leading to the pyrolysis oven. A barrier may be required to prevent small pebbles from blocking the oven entrance.

During drilling, the microprocessor will be provided with a signal proportional to the current drawn by the drill motor. If the current level for stalling is sensed, the drill rotation will be reversed briefly and then forward motion resumed until the desired advance is achieved.

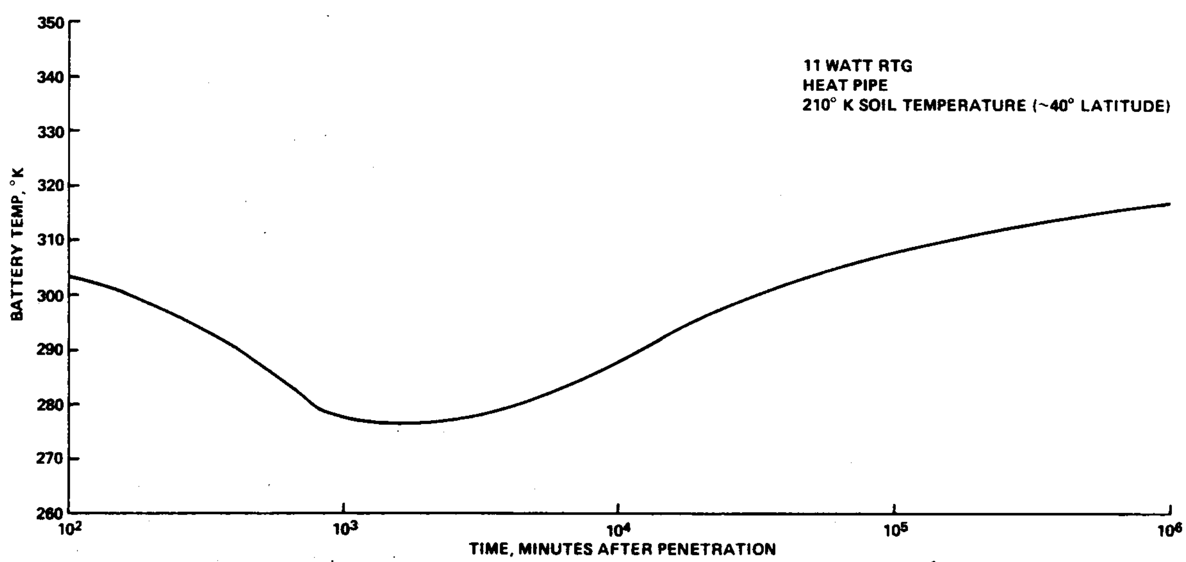


Figure 17.- Battery temperature history.

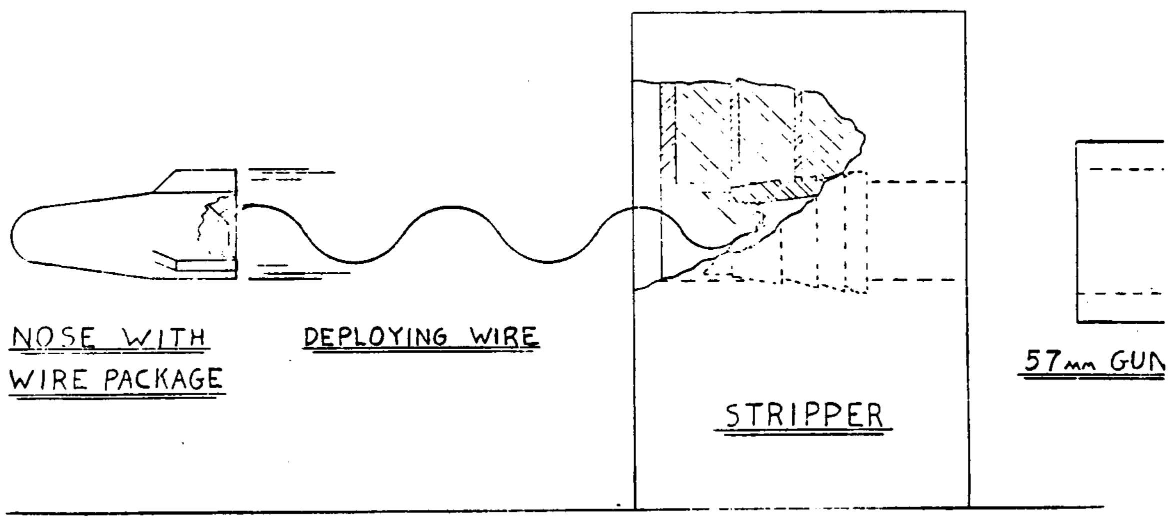


Figure 18.- Laboratory test of umbilical system.

Survivability

The survivability of a Penetrator has two aspects. The first is successful penetration through the surface while maintaining structural integrity. The second is successful operation of the Penetrator subsystems and scientific instruments after the penetration event.

Successful penetration- For penetration into relatively smooth and homogeneous soil, success can be estimated from field test data. For example, an Army program to develop artillery deployed sensors showed 29 of 30 vehicles successfully implanted in soft ground (refs. 45 and 46) and 15 of 18 vehicles successfully implanted in frozen ground (ref. 47). Two failures were only loosely coupled to the ground, and one hit the ground at an abnormal attitude and broke apart. Another example of survivability is the Mars Penetrator tests run during 1976: both vehicles dropped into loess successfully implanted and all four of the vehicles dropped into basalt successfully implanted.

Successful operation- Successful operation after penetration will depend on the proper design of instruments and electronics. High shock load component design has been studied since the incorporation of proximity fuses in artillery shells. Recently developed packaging techniques allow instruments for the Penetrator to be based on miniaturization techniques; thus, increasing the payload for a given volume.

Testing is also of critical importance to the Penetrator's successful operation. During initial field tests of the Army artillery deployed sensors, for example, system failures of 50 percent were recorded. After work to develop a hardened transmitter crystal, a test series into frozen ground showed 100 percent success (ref. 46).

The most extensive use of surface Penetrators was the deployment of intrusion detectors in South East Asia. The gross success rate of the vehicles was about 85 percent (ref. 48). The gross rate is not a good measure of true success, however, because all Penetrators from which transmission was not received were listed as failures without any determination of the failure mode.

Effect of surface rocks- Field drop tests have already demonstrated that Penetrators can survive emplacement in solid basalt formations (ref. 31). Figure 19 is a photograph of a Penetrator that impacted at about 200 m/sec in solid basalt covered by a thin layer of wind blown material. It survived impact and penetration. The question to be addressed here is whether the Penetrator will survive impact against a surface littered with rocks of sufficient size that they are not pushed aside by the impacting Penetrator. A certain size rock might deflect the impacting Penetrator before it enters the soil causing it to become unstable and strike the surface sideways causing catastrophic failure. The cause for this concern was generated by the very rocky terrain observed on the Viking I and Viking II photographs (see fig. 20). This photograph shows a surface littered with rocks giving the impression that a Penetrator impacting in this type of terrain would probably strike a rock,

ORIGINAL PAGE IS
OF POOR QUALITY

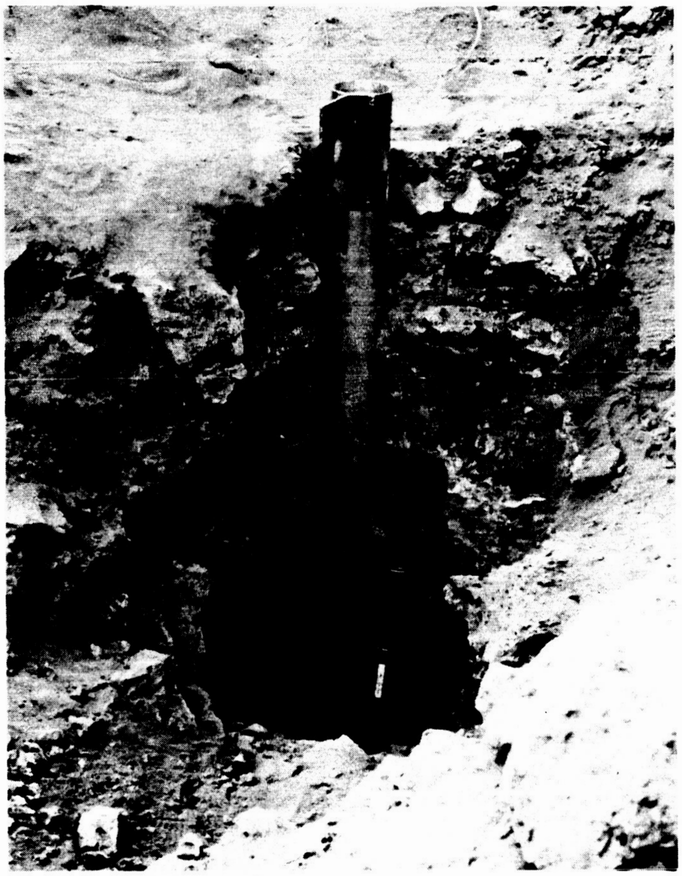


Figure 19.- Penetrator emplaced into basaltic lava flows at Amboy Crater, California, April 1976. Fractured basalt removed from one surface exposing nearly one full length side of vehicle.

Figure 20.- Mosaicked photograph taken by Viking 2's cameras looking northeast to the horizon some 3 km away. The largest rock near the center of the picture is about 2 ft long and 1 ft high.

become unstable, change direction abruptly, and perhaps impact on its side causing rupture. It is, therefore, important to calculate the probability of Penetrator failure due to impact with a surface rock of the proper size to change the direction of flight of the Penetrator.

Two approaches will be taken. First, we consider a size interval of rocks large enough to deflect the Penetrator but not large enough to act as a local solid surface. It is clear that rocks below a certain size D_1 will be pushed aside by the Penetrator thus causing no change in the Penetrator's direction. If we assume that all rocks are tabular in shape, rocks larger than some size D_2 will act as a local solid surface like bedrock and will not be moved appreciably by the Penetrator. Based on impact tests of bedrock (fig. 19), Penetrators will pass through these large rocks, will be stable, and will not fail. Rocks between the sizes D_1 and D_2 are, therefore, considered hazardous to Penetrators for our first estimate of the probability of failure.

Figure 21 shows the size frequency distributions of rocks measured for the Viking I landing site (ref. 49). The number of rocks per unit diameter D per 100 m^2 ($\Delta N/\Delta D$) is plotted against block size D in meters. Therefore,

$$\frac{dN}{dD} = \lim_{\Delta D \to 0} \frac{\Delta N}{\Delta D} = kD^{-\alpha} , \tag{1}$$

and

$$dN = kD^{-\alpha}\, dD \tag{2}$$

α is estimated from figure 21 and 2.92 and k as 4.64. If dA_R is the area of rocks having sizes between D and D + dD in a 100 m^2 area at the Viking I landing site, then:

$$dA_R = \frac{\pi}{4} - D^2\, dN = \frac{\pi}{4}\, kD^{2-\alpha} \tag{3}$$

The total area of all rocks in the 100 m^2 area with sizes between D_1 and D_2 is:

$$\begin{aligned} A_R &= \frac{\pi}{4}\, K \int_{D_1}^{D_2} D^{2-\alpha}\, dD \\ A_R &= \frac{\pi}{4} \left(\frac{K}{3-\alpha}\right)\left(D_2^{3-\alpha} - D_1^{3-\alpha}\right) \end{aligned} \tag{4}$$

The probability of failure is the probability that a Penetrator strikes an area of such rocks so it is given by the ratio of this area to the total area of 100 m^2

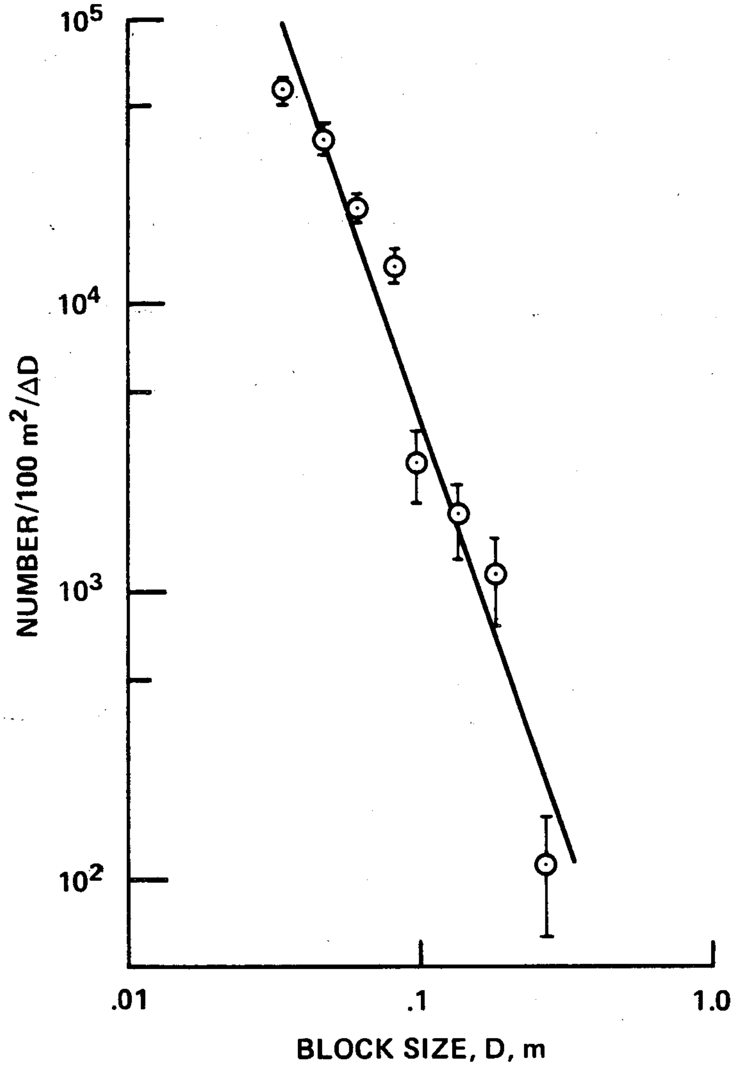


Figure 21.- Size frequency distributions.

$$P = \frac{A_R}{100\ m^2} = \frac{\pi}{400}\left(\frac{K}{3-\alpha}\right)\left(D_2^{3-\alpha} - D_1^{3-\alpha}\right)$$

$$= 0.461\left(D_2^{0.079} - D_1^{0.079}\right) \tag{5}$$

Equation (5) was used to calculate a series of probabilities assuming different sizes intervals $D_1 = D \leq D_2$ were hazardous to the Penetrator. It is convenient to express these intervals in terms of the Penetrator diameter in the form of the ratio $R = D_p/D_1 = D_2/D_p$ where D_p is the diameter of the Penetrator. One value of R fixes the value D_1 and D_2 used on a given calculation since $D_p = 0.09$ m which is the diameter of the Penetrator. For example, a value of $R = 5$ means that all rocks larger than one-fifth the diameter of the Penetrator and smaller than 5 times the diameter of the Penetrator are hazardous. Figure 22 gives a plot of the calculated probabilities for values of R less than 10 for which the probability of failure is only 0.14. Yet, it is clear that this is a very conservative estimate since it is likely that a particle as small as 9 mm will not change the direction of flight of the Penetrator and one as large as 90 cm will certainly be large enough to act as a local solid surface for the Penetrator, thus allowing successful penetration.

As further insight into the probability of failure of a Penetrator impacting at the Viking I landing site, let us now assume that all rocks larger than some size D_1 are irregular in shape so that a Penetrator striking one will always hit an inclined surface and it will ricochet off the rock in such a manner as to change its direction leading to catastrophic rupture. Using the same notation as in the first calculation:

$$dN = KD^{-\alpha}\ dD \tag{6}$$

$$N = K\int_{D_1}^{\infty} D^{-\alpha}\ dD = \frac{K}{\alpha - 1} D^{1-\alpha} \tag{7}$$

Substitution of $K = 4.638$ and $\alpha = -2.921$ and using equation (7), it may be shown that the largest rock in 100 m^2 of the Viking I landing site is 1.58 m. Substitution of this into equation (5) gives:

$$P = 0.461(1.58^{0.079} - D_1^{0.079}) \tag{8}$$

Equation (8) permits a calculation of the probability of striking a rock of size larger than D_1. Results are plotted in figure 23. There is only 0.157 probability that the Penetrator will strike any irregular rock larger than 1 cm. Certainly such a rock is not harmful to the Penetrator. If we consider rocks comparable to the size of the Penetrator (0.09 m) to be harmful, there is only a 0.09 probability of failure for impact at the Viking I landing site.

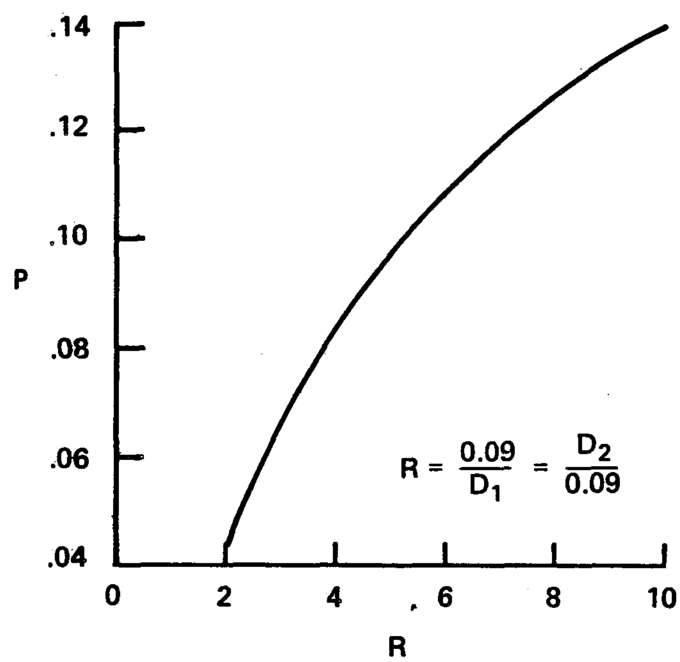


Figure 22.- Probability of failure for hitting block in size range $0.09/R \leq D \leq 0.09R$.

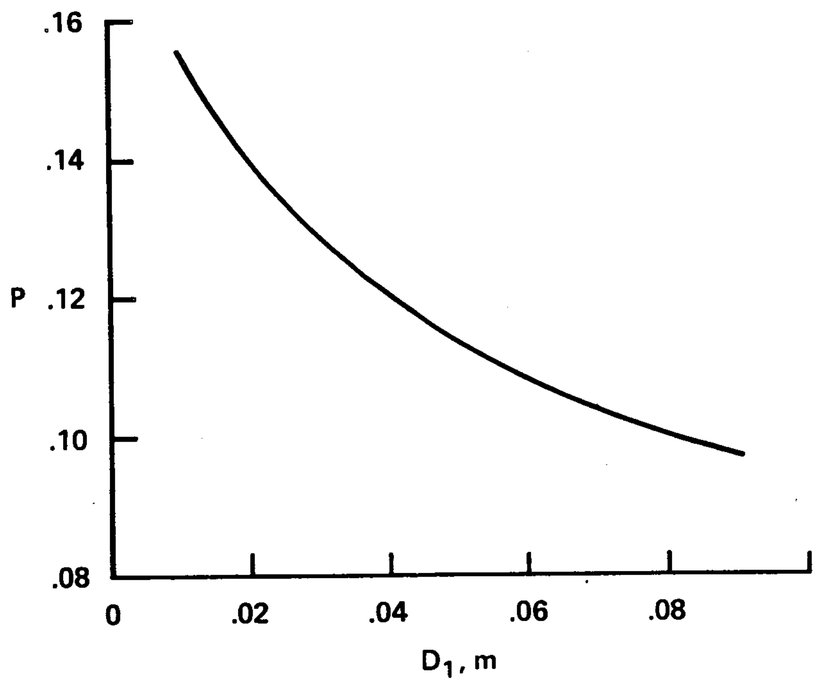


Figure 23.- Probability of failure for hitting block in size range $D \geq D_1$.

Our conclusion at this time is, therefore, that surface rocks observed at the Viking I landing site do not appear to be an undue threat to the stability of the impacting Penetrator. Rather wide limits on the size interval for rocks hazardous to the impacting Penetrator were assumed for these calculations. Further laboratory and field tests are required to confirm actual, more realistic limits. Moreover, only rocks actually on the surface were assumed harmful whereas rocks embedded in the soil at shallow depths might also cause defection in the path of the Penetrator although the field test (fig. 19) indicates that soil already penetrated has a stabilizing effect when the Penetrator strikes a subsurface rock surface. Additional field test results are required to assess these problems.

Effect of winds- A thick wind layer at Mars can be assumed to translate the Penetrator parallel to the surface while the Penetrator maintains a local vertical orientation. With this conservative assumption, the angle of attack at impact is a function of the impact speed and the wind speed. Through empirically derived equations (ref. 50) these impact conditions can be related to the depth of penetration and the g-load on the forebody for a given soil classification. Figure 24 shows the data for impact into sand and figure 25 for impact into lava.

The maximum angle of attack for acceptable penetration is a function of the bending loads and moments applied to the Penetrator. Thus, the Penetrator configuration (e.g., nose shape, fineness ratio, wall thickness, etc.) and impact material (which effects the rebound speed, i.e., bounces back out of material, and the ricochet speed, i.e., deflects off the surface) have significant influences on the angle-of-attack limit.

While there is no angle-of-attack test data directly related to this Penetrator, the data that do exist (small size and very high impact speeds into reinforced concrete) indicate that an angle-of-attack limit not less than 5° could be expected. For the baseline impact speeds, 135-160 m/sec, a wind of about 14 m/sec could be tolerated. Designing the Penetrator to survive greater forebody g-loads would allow the impact speed to rise and the tolerable wind would rise correspondingly (e.g., an impact speed of 450 m/sec would allow winds of 40 m/sec). To survive winds over 50 m/sec would necessitate the acceptance of greater angles-of-attack. Part of the testing activity planned to support the Penetrator mission will address this problem and determine the angle-of-attack limit.

The end result of the angle-of-attack limit determination will be a maximum allowable wind at the time of impact. In turn, this will constrain the time periods during the Mars year when the Penetrator can be used, as well as the impact location. Present Viking results indicate steady winds of 10-15 m/sec with gusts to about 20 m/sec (ref. 51) which would correspond to velocities at the top of a 1-km-deep boundary zone of 20-60 m/sec (ref. 52). Since the Penetrator pitching frequency will be on the order of 0.3 Hz, the Penetrator will experience about two cycles of pitch motion during this zone. That is sufficient for the Penetrator orientation to partially adjust to the winds; thus, reducing the angle of attack at impact to roughly 40 percent of that value experienced for a zero thickness boundary layer.

The conclusion reached is that proper design of the Penetrator, selection of impact site and choice of impact speed will alleviate any problems with failure due to a large angle of attack at impact.

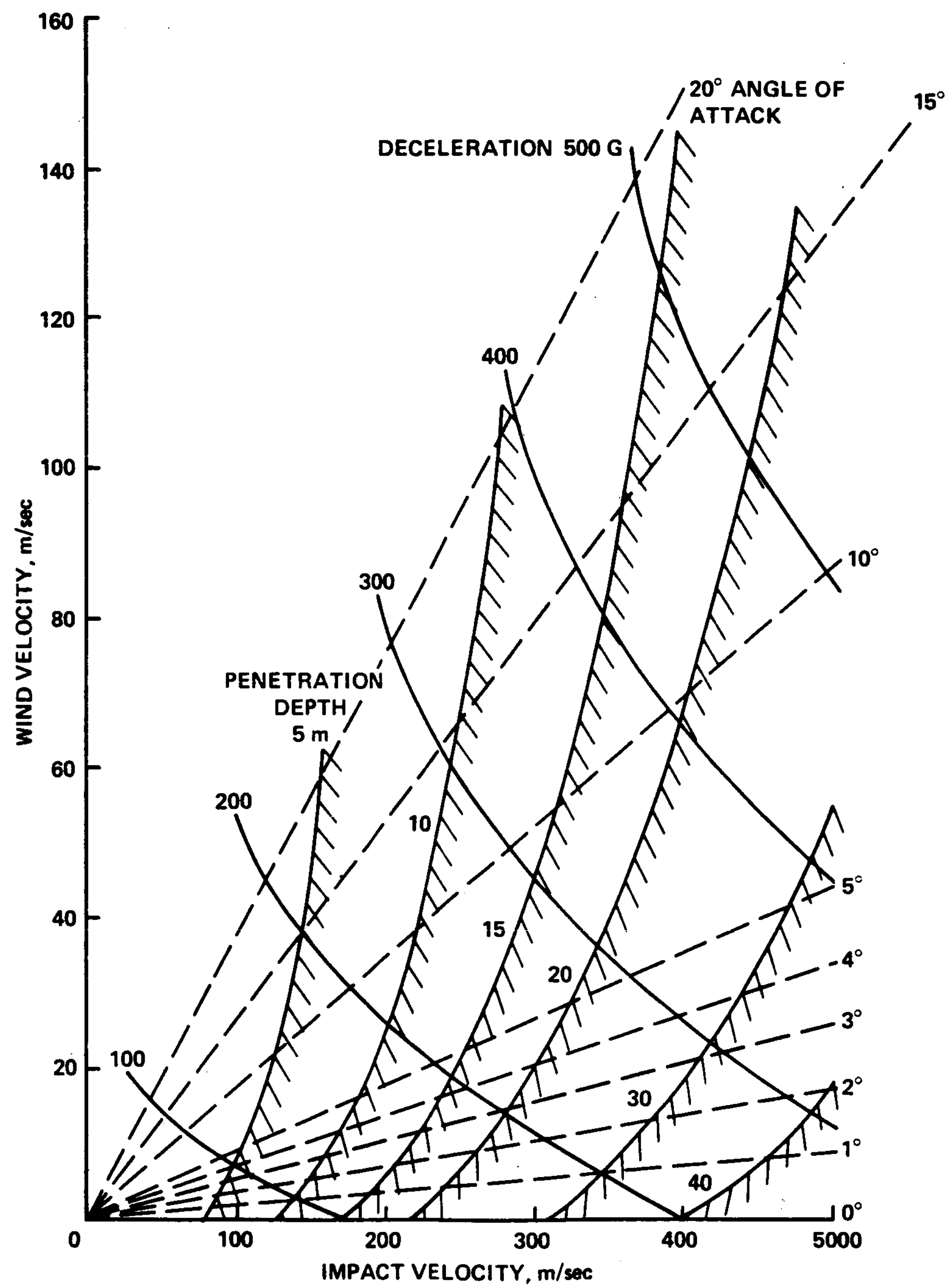


Figure 24.- Mars penetrator forebody environment impact in sand, S = 15.0, no terrabrake.

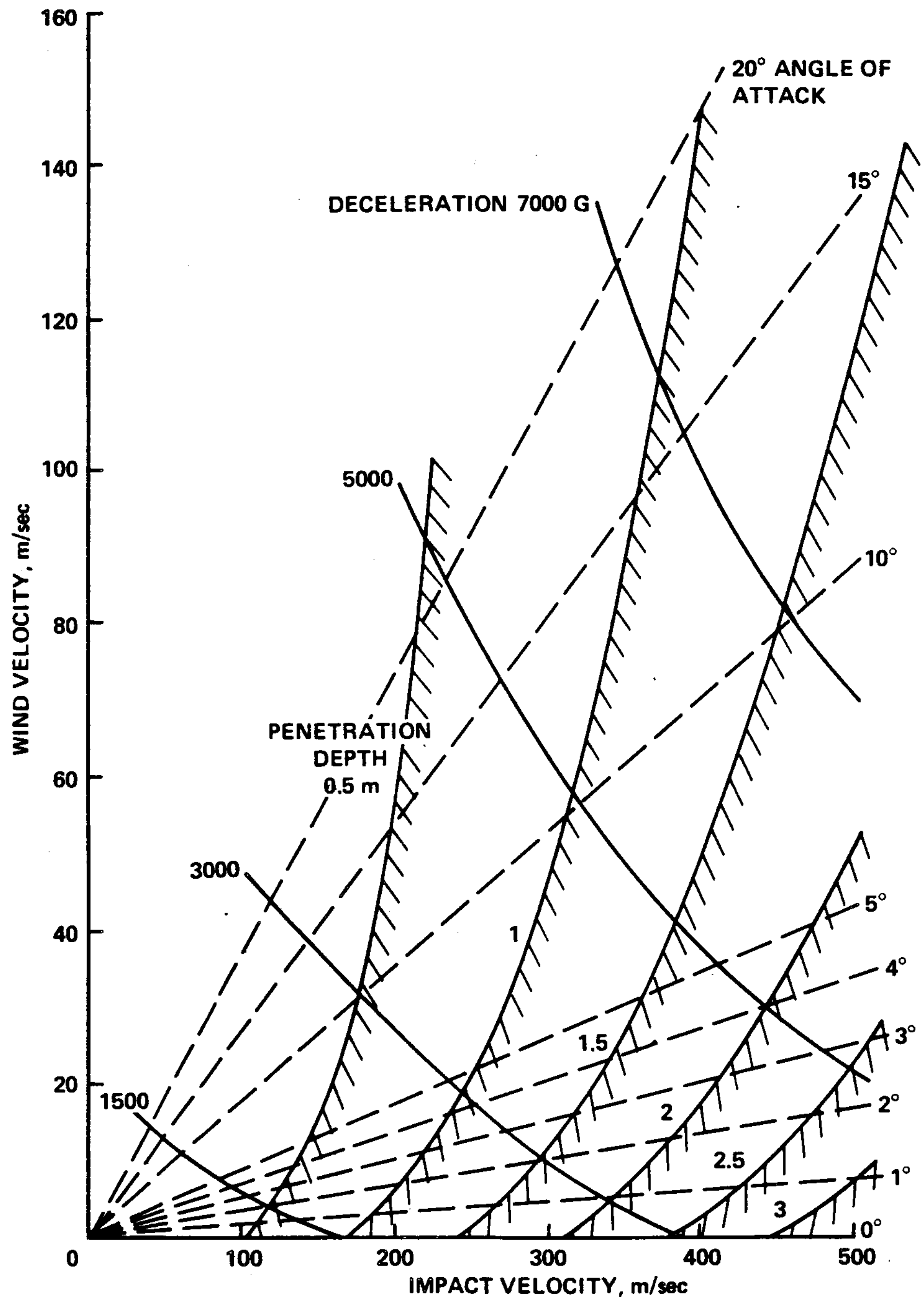


Figure 25.- Mars penetrator forebody environment impact in lava, S = 1.0, no terrabrake.

OPERATIONS

Data Collection

All data collected by the Penetrator science instruments will be stored in the bubble memory for relay to the Orbiter during discrete communication periods. During the main period of Rover operations, the relay Orbiter will be in low circular orbits which will allow Penetrator data relay once or twice each sol.

However, operation of the Penetrator data link may be significantly different early in the mission. Baseline mission plans call for the Penetrator to be separated two days prior to Mars orbit insertion. Since the initial orbit will have a period of 5 days, daily communication with the Penetrator will certainly not be possible and in fact no communication may exist until the low altitude circular orbits are established some 6 months later. The data collection plan for Penetrator science and orientation measurement must take this into account.

Science measurements— Once Penetrator site selection and Orbiter constraints have been established the potential Penetrator relay links can be defined. Until such time, the baseline mode, discussed in this section, assumes storage of all data for the entire time (about 6 months) until the daily data relay links are possible. Thus, one-time only measurements are given priority in the memory. Storage for each critical measurement will be allotted with no over-ride from other instruments. After the relay orbit is established and the Penetrator memory read out, a continuous mode of operation will be initiated.

The data which can only be obtained at impact (deceleration), or shortly after impact (heat flow during cool-down), are given first priority. The Accelerometer is turned on when the Penetrator is separated from the Orbiter. Data is stored in continuously circulating buffers until impact. The measurement continues for 0.3 sec after impact. The heat flow measurement begins within 30 sec of impact and continues at the rate of one measurement per min for the first day. The frequency of measurements then decreases to a low level for the rest of the mission.

Another event coincident with implantation is the predicted start of the Mars dust storm period. Thus meteorological measurements would begin shortly after impact. Pressure, humidity, wind speed and direction (if possible) and temperature data would be stored as would solar extinction data. These data would be taken throughout the 6 months at preset time intervals to fill the allotted storage arrays.

The remaining memory would be reserved for seismic activity. A decision would have to be made between recording one event in detail (i.e., time history) or recording occurances (e.g., peak value, average value, and duration above some level for each event) to provide statistical information over the 6 months.

After the orbiter is established in a low circular orbit, it would send a command to the Penetrator to read out its memory and the orientation of the Penetrator. Magnetic, meteorological, seismic, heat flow, and solar photometry measurements would be initiated on a continuous basis as shown in figure 26. The data would be stored on the Penetrator and transmitted to the Orbiter during the two 10-min communication periods each sol.

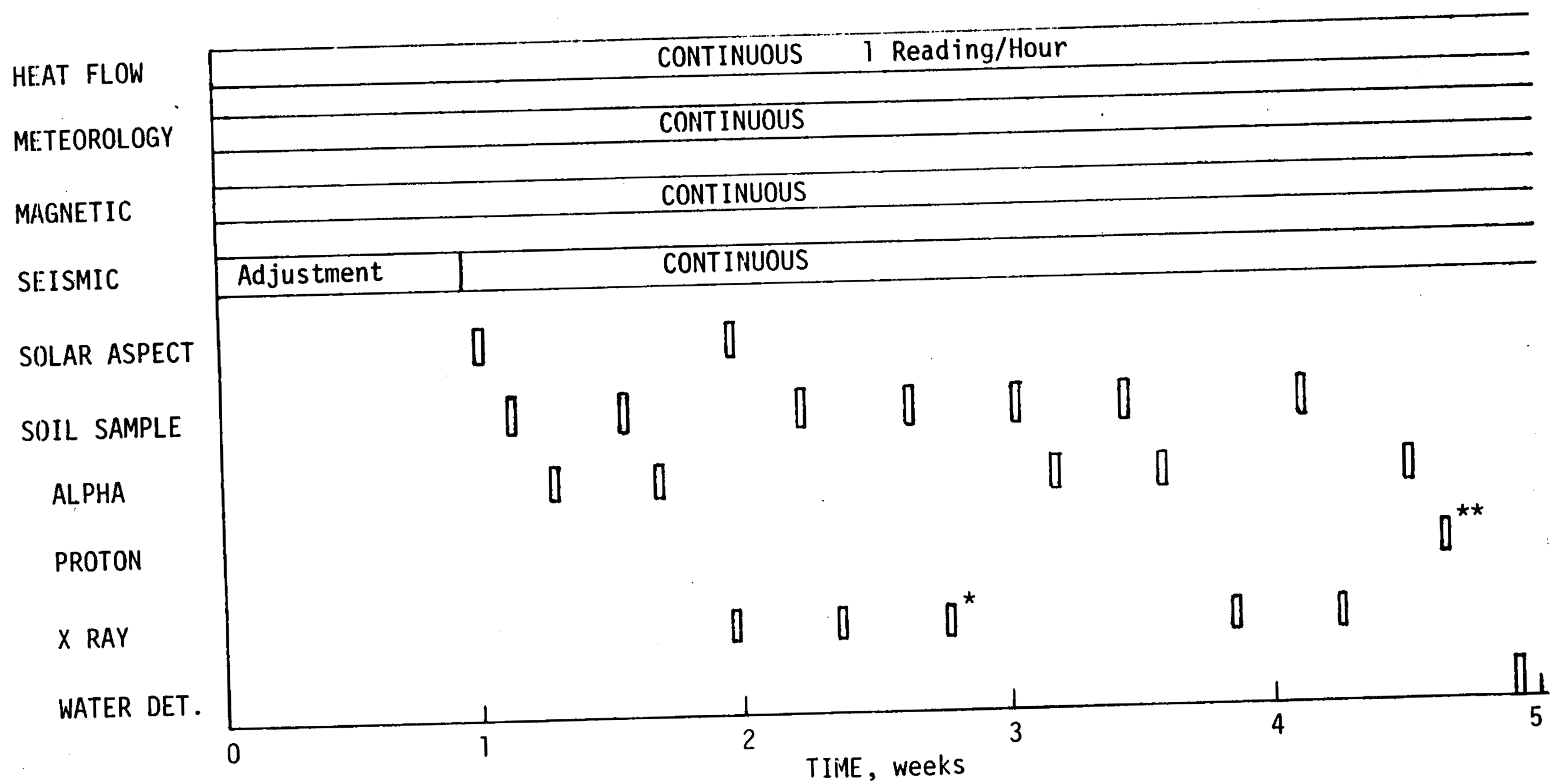
Soil sampling also begins during this time period. The sampling mechanism is operated for 600 sec each day followed by an alpha particle scattering measurement. Soil sampling is repeated until the alpha particle experiment indicates a sample is present. The sampler is activated again, and the soil sample is examined by the X-ray fluorescence experiment. When the X-ray experiment indicates a full sample has been obtained, this sample is dumped and the sampling measurement sequence is repeated to obtain an uncontaminated sample. Each soil sampling measurement cycle will take a minimum of two days plus the time for date evaluation. The soil sampling and scattering measurement are repeated two times for a total of four alpha-proton, X-ray measurements. The final sample is dumped into the differential thermal analyzer for examination of water content.

Orientation determination— The penetrator afterbody will be equipped with a "sundial" for determining the azimuth of the afterbody after impact. As each of several slits of unequal width expose a sensing photo-diode to sunlight, the total illumination from the sky and sun will be registered. When the sensor is shaded by the slit structure, only the sky-scattered illumination will be registered. Since the sampling times (in terms of sun azimuth angle relative to Mars geometric north) will change from sol to sol, a complete definition of the slit array orientation will be acquired over the first few months of operation.

The orientation of the longitudinal axis of the afterbody will affect the azimuth determination. Given sufficient time that effect can be determined and the afterbody elevation angle defined. However, the determination of both the elevation angle and the azimuth angle of the afterbody is simplified and made more accurate by a separate determination of the elevation angle. This can be done with a set of nominally horizontal slits or by means of a biaxial spirit level analogous to the bubble tilt meter proposed for the seismometer.

The above techniques are capable of determining the afterbody axis to an accuracy of less than 1° (more probably to within 0.25° after a sufficiently large number of observations have been recorded).

The forebody azimuth orientation is less satisfactorily determined. Reliance apparently must be placed on many observations of test penetrator twisting motions. Although numerous accurate observations have not been made, it is the observation of experimenters that the scratch marks of many recovered penetrators indicate that there is no tendency to twist about the longitudinal axis. Therefore, the azimuth of the afterbody should be maintained within perhaps 2°.



*If sample is obtained, then dump.
**If sample is satisfactory, dump to water detector.

Figure 26.— First month after impact.

The tilt of the forebody will be determined either from the angular motion required to erect the seismometer to plumb or from the electrical plumb signals if internal biasing is the selected means of operation. In either case, the orientation relative to local vertical will be determined to within 0.1°.

Data Relay

Baseline— A few minutes before interrogation by the Orbiter is to start, the Penetrator timer turns on the command receiver. Similarly, the Orbiter command transmitter is turned on to be prepared for the encounter. When the Orbiter elevation angle is greater than 20° (to avoid multipath losses and irregular terrain), the Orbiter addresses the Penetrator. When the Penetrator detects its address, it turns on its transmitter and acknowledges the address. The Orbiter then commands the Penetrator to update its clock timer and to make any changes in its scientific data collection mode, and then to read out the stored data during the period for which a good link is expected. The Penetrator transmits the data until either all the data are transmitted or the commanded link duration is reached. Any data remaining in memory will be read out next time before any subsequently collected data. Thus, the data will always be transmitted in the order acquired.

On board the Orbiter, the data are usually stored for subsequent transmission to the Earth. Real-time transmission may occur, but there is no major gain from that mode. After being received and recorded by the Deep Space Network (DSN), the data are transmitted to Ames for reduction to scientific data. During the first few months, the Principal Investigators, or their representatives, are stationed at Ames to monitor performance and work with Ames in selecting operating strategy for each of the Penetrators. Commands are selected and transmitted to the DSN after coordinating with the Mission Control Center at JPL.

Multiple channels— Since the Penetrators will be dispersed in network arrays selected for seismic, magnetic, and meteorogical definition of Mars, it is possible that local (hundreds of kilometers) as well as global (thousands of kilometers) networks will be desired. The Penetrators of the local network will have simultaneous data relay requirements. The polar Orbiter is the prime relay link for the Penetrators and serves as the back-up relay for the Rover and deployed science packages (DSP). These ground stations may also be in view during the Penetrator telemetry period. Thus, communications must be planned and designed to anticipate Orbiter relay requirements. The baseline Orbiter has 2 receivers: one is dedicated to the Rovers, and the other to the Penetrators and DSPS. These receivers are not transferable in performance, without major design impact.

In order to support simultaneous transmission from closely arrayed ground stations (Penetrators and/or Rover deployed stations) multiple telemetry carrier channel frequencies are necessary. Furthermore, even if only one channel was required, more than one channel would provide both mission flexibility and redundance which are of major importance to such a mission.

Where only one receiver is available, there is no backup capability for the high latitude Penetrators.

Since the transmission bandwidths are relatively narrow, the requirement for simultaneous transmission can be accomodated without major design impacts on the Penetrator transmitter or the Orbiter receivers. The Penetrator transmitter will have a maximum frequency uncertainty of ±10 parts per million or ±4 kHz over the mission life. At 2500 bps, with rate 1/2 coding, ±15 kHz will accommodate the third harmonic of the modulated spectrum. Thus, if channels were spaced on 44-kHz centers, a 6-kHz guard band would exist for worst case uncertainties between the third harmonics of adjacent channels. Four such channels can be contained in 150 kHz which can readily be scanned by the type of telemetry receiver invisioned for the mission using a single receiving antenna. Penetrator transmitter channels can be permanently set by using different reference crystals or one of the channels could be synthesized by command, if a modest incrase in transmitter complexity was allowed. Failure of a receiver could be accommodated by a reduced data rate return through time sharing.

In addition to the receivers, the Orbiter would provide Penetrator command and telemetered data storage for relay to Earth. Commanding up to four separate Penetrators will require a carefully programmed operational sequence; but a single command frequency could be used by giving each Penetrator a unique command address. Data storage on the Orbiter does not appear to be a problem since each nominal 10-min communication period produces 1.5 million bits per Penetrator; thus, a local network would produce only about 6 million bits on 2 of the 12 orbits per sol.

BIBLIOGRAPHY

1. Space Science Board: Opportunities and Choices in Space Science. National Academy of Science, 1974.

2. Mars Science Advisory Committee: Mars: A Strategy for Exploration. Study Report, November 1973.

3. Friedlander, A. L.; Hartmann, W. K.; and Niehoff, J. C.: Pioneer Mars 1979 Mission Options. Science Application, Inc. Report SAI 120-M1, January 1974.

4. Mars Science Advisory Committee: Exploration of Mars After 1976. Working Report, April 1974.

5. Ames: Mars Science Missions in the Post-Viking Era: Possible Contributions of Pioneer-Type Missions. Working Report, August 1974.

6. Hughes Aircraft Co.: Pioneer Mars Surface Penetrator Mission - Mission Analysis and Orbiter Design. Summary Report NAS2-8424, August 1974.

7. Sandia Labs.: Mars Penetrator: Subsurface Science Mission. Contractor's Report No. SAND 74-0130, August 1974, NASA-Ames Contract No. RA88365A.

8. Kraemer, R. S.: Planetary Missions in the Shuttle Era. vol. 40, Science and Technology, Proceedings of the 13th Goddard Memorial Symposium, April 11, 1975.

9. Quaide, W. L.; Oberbeck, V. R.; Morrison, R. H.; Aggarwal, H. R.; and Blanchard, M. B.: Mars Penetrators: A Preliminary Analysis of Their Value for Near Surface Science. Intnl. Colloq. of Planetary Geology, Expanded Abstracts, Rome, Italy, September 22-30, 1975.

10. Jet Propulsion Lab.: Mars Polar Orbiter/Penetrator Study Report. Rep. 760-129-B, October 30, 1975.

11. Cutts, J. A.: Evaluation of the Feasibility of Experiments for a Mariner Class Mars Polar Orbiter Mission with Multiple Penetrator Surface Probes. Science Applications, Inc. Preliminary Report, December 1975.

12. Quaide, W. L.; Oberbeck, V. R.; Blanchard, M. B.; and Morrison, R. H.: Penetrators: Multiple Subsurface Probes for Mars and Other Planetary Bodies. vol. 56, Trans. of Am. Geophys. Union, 1975.

13. Quaide, W. L.; Oberbeck, V. R.; Blanchard, M. B.; and Reynolds, R. T.: Status Report on Feasibility of Using Penetrators in Planetary Exploration. (Memo to NASA-Hq. Planetology Program Principal Investigators from NASA-Ames, May 14, 1976).

14. Spaceflight: A New Concept in Planetary Probes-The Mars Penetrator. Spaceflight, vol. 18, no. 12, December 1976, pp. 432-434.

15. Ball, G. G.; and Bird, T. H.: Requirements and Capabilities for Planetary Missions: Mars Polar Orbiter/Penetrator 1981. NASA SP 43-27, vol. 2, 1976.

16. Spudis, P. V.; and Greeley, R.: Surficial Geology of Mars: A Study in Support of a Penetrator Mission to Mars. NASA TM X-73,184, 1976

17. Simmons, G.: Correspondence — Mars Penetrators: Three Entry Schemes. Airflight, February 1977.

18. Ames: Mars Surface Penetrator Mission Instrument Status. Working Report, February 1975.

19. Ames: Penetrator Study Progress. Working Report, May 1976.

20. Westphal, J. A.; Currie, D.; Fruchter, J.; Head, J.; Helsoy, C.; Lister, C.; Niehoff, J.; and Tillman, J.: Final Report and Recommendations of the Ad Hoc Surface Penetrator Science Committee. NASA-OSS, Planet. Prog. Div., August 1976.

21. Blanchard, M. B.; Oberbeck, V. R.; Bunch, T. E.; Reynolds, R. T.; Canning, T. N.; and Jackson, R. W.: FY 1976 Progress Report on a Feasibility Study Evaluating the Use of Surface Penetrators for Planetary Exploration. NASA TM X-73,181, 1976.

22. Terrestrial Body Science Working Group: Report of the Mars Subgroup. Preliminary Report, 1976.

23. Carr, M. H.: Martian Fluvial Features. American Astronomical Society, Division for Planetary Sciences, 8th Annual Meeting, Honolulu, Hawaii, January 19-22, 1974.

24. Keihm, S. J.; and Langseth, M. G.: Modeling Studies for a Mars Penetrator Heat Flow Measurement. NASA CR-151946, 1976.

25. Canning, T. N.: Personal Communication, 1977.

26. Greeley, R.; and Carr, M. H.: A Geological Basis for the Exploration of the Planets. NASA SP-417, 1976.

27. McNeil, R. L.: Rapid Penetration of Terrestrial Materials: The State of the Art, Conference on Rapid Penetration of Terrestrial Materials, Texas A&M Univ., February 1-2, 1972.

28. Johnson Space Center: Lunar and Planetary Sciences Div.: Consideration of Sample Return and the Exploration Strategy for Mars. March 1977.

29. Blanchard, M. B.; and Shade, H. D.: The Effect of a Planetary Surface Penetrator on the Soil Column Surrounding the Impacting Body. NASA TM X-62,428, 1975.

30. Shade, H. D.: Preliminary Analysis of Soil Modification Found After 0.58-Scaled Penetrator Impaction on August 4, 1975, at Sandia Lab., New Mexico. LFE Report TLW 6142A, 1975.

31. Blanchard, M.; Bunch, T.; Davis, A.; Shade, H.; Erlichman, J., and Polkowski, G.: Results of Analyses Performed on Basalt Adjacent to Penetrators Emplaced into Volcanic Rock at Amboy, California, April 1976. NASA TN in preparation.

32. Bunch, T. E.; Quaide, W. L.; and Polkowski, G.: Initial Basalt Target Site Selection Evaluation for the Mars Penetrator Drop Test. NASA TM X-73,111, 1976.

33. Greeley, R.; and Bunch, T. E.: Basalt Models for the Mars Penetrator Missions: Geology of the Amboy Lava Field, California. NASA TM X-73,125, 1976.

34. Polkowski, G.: Procedures for Preserving Subsurface Fabric and Textures in Soil Adjacent to an Impacted Penetrator. LFE Corp. Report TLW 6149, 1976.

35. Shade, H. D.; and Polkowski, G. R.: Analysis of Core Material Obtained from McCook Nebraska. LFE Report TLW 6148B, 1976.

36. Polkowski, G.: Evaluation of Double-Theodolite Methods for Helicopter Positioning and Wind-Velocity Measurements. LFE Corp. Preliminary Report, February 11, 1977.

37. Blanchard, M.; Bunch, T.; Davis, A.; Kyte, F.; Shade, H.; Erlichman, J.; and Polkowski, G.: Results of Analyses Performed on Soil Adjacent to Penetrators Emplaced into Sediments at McCook, Nebraska, January 1976. NASA TN D-8500, 1977.

38. Byers, R. K.; Chabai, A. J.; and Walsh, R. T.: Predictions of Projectile Penetration Phenomena and Comparison with Experiments in a Soil Medium. Sandia Labs. Report No. SAND 75-0174, May 1975.

39. Anderson, Donald: Personal Communication 1977.

40. Dyal, Palmer: Personal Communication 1977.

41. Anderson, D. M.; South, J. F.; and Tice, A.: Mars Penetrator Water Detector. Working Report, May 1976.

42. Economou, T. E.; and Turkevich, A. L.: An Alpha Particle Instrument with Alpha, Proton, and X-Ray Modes for Planetary Chemical Analyses. Nuclear Instruments and Methods, vol. 134, 1976, pp. 1-10.

43. Currie, D.; and Head, J. W.: Imaging Experiment for Planetary Penetrator Afterbodies. Mars Working Report, 1976.

44. Bentley, R. D.; and Campbell, A. B.: The Mars Penetrator Telemetry and Control System. Intnl. Telemetering Conference, Silver Spring, Maryland, October 14-16, 1975.

45. Test Report: Soft Ground Test (Phase B) of Terminal Delivery Vehicle (High Speed), December 22, 1972.

46. Test Report: Soft Ground Test (Phase D) of ADS in Terminal Delivery Vehicle T-9A and T-98WA, April 25, 1973.

47. Test Report: Frozen Ground Test (Phase C) Terminal Delivery Vehicle (High Speed), March 19, 1973.

48. Personal Communication from Wayne Olson, Sandia Laboratories, April 27, 1977.

49. Mutch, T. A. et al.: The Surface of Mars: The View from the Viking I Lander. Science, vol. 193, no. 4255, pp. 791-801, Aug. 27, 1976.

50. Young, C. W.: Emperical Equations for Predicting Penetration Performance in Layed Earth Materials for Complex Penetrator Configurations. Sandia Labs Report SC-DR-72-0523, 1972,

51. Tillman, James: Personal Communication 1977.

52. Pollock, James: Personal Communication 1977.

1. Report No.	NASA TM-73,243
2. Government Accession No.	
3. Recipient's Catalog No.	
4. Title and Subtitle	MARS SURFACE PENETRATOR — SYSTEM DESCRIPTION
5. Report Date	
6. Performing Organization Code	
7. Author(s)	Edited by Larry A. Manning
8. Performing Organization Report No.	A-7044
9. Performing Organization Name and Address	Ames Research Center Moffett Field, Calif. 94035
10. Work Unit No.	186-68-76
11. Contract or Grant No.	
12. Sponsoring Agency Name and Address	National Aeronautics and Space Administration Washington, D.C. 20546
13. Type of Report and Period Covered	Technical Memorandum
14. Sponsoring Agency Code	
15. Supplementary Notes	

16. Abstract

A Penetrator network is vital to a geophysical understanding of Mars and an invaluable adjunct to an Orbiter/Rover combination in an intensive study of Mars. This report presents a point design of a Penetrator system for a 1984 Mars mission. The point design, including the strawman payload and its derivation from a geophysical science rationale, is described. The subsystems used in the point design are a combination of tested and conceptual designs. The data handling and communications plans are presented to allow consideration of the requirements placed by the Penetrator on the Orbiter and ground operations. While elements of the concept still need extensive testing in simulated mission environments, the point design provided in this report is technically feasible and the payload selection scientifically desirable.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Mars Penetrator System description	Unlimited STAR Category - 91

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	88	$4.75

*For sale by the National Technical Information Service, Springfield, Virginia 22161