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Planetary Mission Summary: Mars Rover

Jet Propulsion Laboratory
California Institute of Technology
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Foreword

This volume presents one of a collection of planetary mission definitions which summarize what is now known about several future missions of current interest in NASA planning. Since the missions are at various stages in the planning process, the firmness and validity of the information vary. The level of detail presented, however, is uniformly concise and reflects our present best estimate of the likely characteristics of each mission. Most of the information comes from JPL technical studies sponsored by NASA.

For this mission, the choice of baseline reflects our initial judgment as to what level of performance gives a viable combination of scientific potential, development schedule, and cost. Variations from the baseline, such as launching in a later year or using a smaller or larger spacecraft, are included where they have been studied. Our objective has been to compile in brief form the main technical conclusions of recent mission studies in order that these results may interact with the broader questions of scope, pace, and priorities in the planetary exploration program as a whole.

W. H. Pickering
Director, Jet Propulsion Laboratory

Mars Rover

Launch Date: January 1984

Landing Date: October 1984

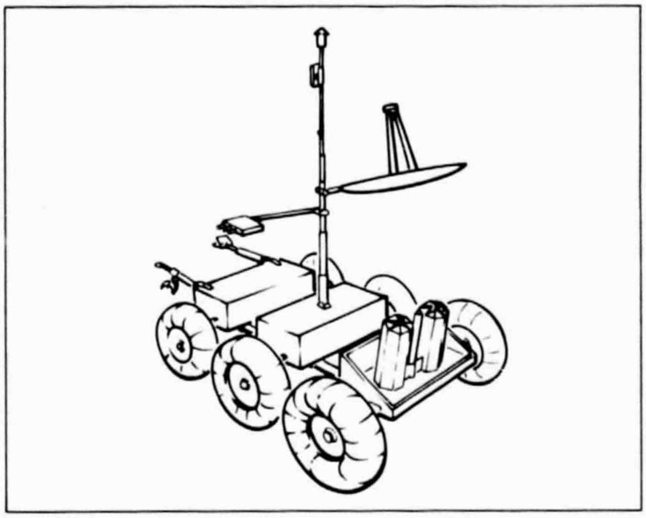
Surface Lifetime: 12–18 months

Injected Mass: 4000 kg

Rover Mass: 550 kg

Instrument Mass: 70 kg

Launch Vehicle: Shuttle/IUS, one launch



Objectives:

To characterize surface geomorphology, chemistry, volatiles content, and environments for life. To aid in extending the point data of stationary landers and the survey data of orbiters to a statistically meaningful determination of Martian surface properties.

Typical Science Investigations:

Panoramic and closeup imaging
Chemical composition measurement
Mineralogy of soils and rocks
Traverse geophysics
Volatiles measurement
Organics and life detection (optional, not included in baseline)

Mission Description:

Rover, landed by Viking-type descent systems, travels slowly for several hundred km in about a year, with many stops for imaging and other measurements. Ground command is used to revise path, select experiments, and update stored programs to make the missions as adaptive as possible subject to rover constraints. Actual range traversed will be dependent on the science operations implemented along the traverse and on the terrain characteristics encountered by the vehicle. Rover will be capable of negotiating obstacles on the scale of 1 meter.

Status:

Conceptual mission and vehicle studies completed. No study effort currently underway.

Estimated Funding:

(1) Launch vehicle and DSN-support funding excluded.

(2) Long lead time for rover development model testing.

(3) Inflated dollars equal 5% annual inflation.

Fiscal year	79	80	81	82	83	84	85	86	87	Total
FY75 dollars (millions)	16.4	71.5	110.0	143.0	99.0	66.0	22.0	16.6	5.5	550.0
Inflated dollars (millions)	19.4	91.0	147.1	200.7	145.9	102.1	35.7	28.3	9.9	780.1

Mars Rover

I. Science

A. Rationale

Direct measurements on the Martian surface are essential to give data on the composition, accretion and differentiation history, and surface evolution of Mars. Stationary landers can make such measurements at a few isolated points located at random within selected target regions, but to make a statistically meaningful determination of surface properties and processes we will need mobility.

Even at the 100-m resolution limit achieved by Mariner 9, one sees a variety of Martian landforms. They reflect an array of geologic and atmospheric processes, some of which have earthly or lunar analogs and some of which do not. Volatiles, including water, and winds appear to have had major roles in shaping parts of the surface; life, if present at all on Mars, is likely to be adapted to the local environments so created. Therefore, unless life is ubiquitous on Mars, the search for it must include seeking and understanding these favorable sites. Such a search inherently demands mobility.

Two kinds of surface investigations are thus required: first, a continuous recording of properties expected to be typical in each province explored, and second, a survey of geologically or environmentally atypical sites, either selected in advance on the basis of overhead mapping or found as targets of opportunity. Lunar surface exploration has followed a similar rationale.

B. Objectives

Possible scientific objectives for a Mars rover are as follows:

(1) To determine surface and atmospheric properties along a traverse of major provinces on Mars (hundreds of km), covering as many different landforms as possible.

(2) To sample surface and near-surface (a few cm) materials for chemical, mineral, and volatile content at hundreds of points along the traverse.

(3) To identify targets of opportunity, go to them, and explore special environments, including those that might harbor life.

(4) To detect and characterize life if it is present. (May be dictated by results from Viking '75.)

This mission has not been studied in sufficient depth to quantitatively define science objectives and payload. The subsequent payload and mission description, defined from rover studies performed several years ago, are only illustrative of the characteristics and capabilities desired. As such, the intent here is to present a rover mission with known general characteristics to allow for its consideration in pl nning a Mars strategy for the mid-1980's.

C. Typical Measurements and Payload Instruments

1. Imaging. The rover should carry one or more panoramic photofacsimile cameras. The panoramic camera is the primary instrument for geological reconnaissance, orientation, and navigation of the rover (Ref. 1). The Viking lander cameras, which are multispectral and can scan a complete horizontal panorama with a vertical field of 60 deg and a best angular resolution of 0.04 deg, could be used. Tests have shown that the Minifax camera (Ref. 2), which is much smaller and lighter than the Viking camera but lacks some of its versatility, would also give acceptable navigation performance for a rover.

In addition to the panoramic camera, the rover should have a closeup imaging system for viewing objects at a scale of millimeters to tens of microns. This could be a

TV camera (Refs. 3 and 4). A scanning electron microscope should also be considered.

The requirements for photometric, dimensional, and spectral fidelity and resolution for both the panoramic and closeup cameras can be derived from simulation experiments as described in Refs. 3, 4, and 5. The required performance is readily achievable in daylight on Mars, so long as the image transmission rate is limited to match the telecommunications bandwidth.

2. Chemical composition sensing. Alpha-particle interactions, X-ray fluorescence, and spectrometry of natural gamma rays have all been used to detect elements on the Moon and Venus. A combined alpha/X-ray instrument has been proposed for Mars (Ref. 6) and would be very appropriate for a rover.

3. Mineral species detection. Some data on mineral phases can be obtained by X-ray diffractometry. However, in view of the widespread aeolian transport of dust on Mars, random soil samples may include mineral grains from many sources, and hence their average mineralogy may not be very informative (some lunar breccias present a similar problem). Since the preparation of thin sections is probably out of the question, recognition of individual mineral species in a mixed soil aggregate will have to depend on optical or electron microscopy (Ref. 7), and will be imperfect. Recognition of minerals in rock specimens may be possible using a combination of indirect techniques along with the microscopy. For example, it is conceivable that Mössbauer gamma-ray spectrometry could be used *in situ* to detect the oxidation states of iron in Martian rocks—a fundamental discovery if it could be achieved.

4. Volatiles detection. Very small and simple detectors can be used for the approximate measurement of atmospheric and soil humidity. For more quantitative measurements, determination of the volatile species present, and assessment of how they are bound onto or into the solids, pyrolysis with differential thermal analysis and gas chromatography could be used. More exotic methods, such as "zapping" the soil *in situ* with a laser and observing the products, have been proposed but not yet developed into flyable instruments.

5. Geophysical measurements. Heat flow, passive and active seismometry, gravimetry, magnetometry, and electromagnetic sounding are all very desirable measurements for a Mars rover traverse (Ref. 8). Unfortunately, some of these measurements are quite difficult to make with simple remotely controlled equipment; the geophysical performance of the long-range rover may therefore be quite limited. Measurements of the near-surface dielectric constant may be possible, using the landing radar in a sounding mode. If this proves to be feasible, the rover should carry the radar along rather than leaving it at the landing site.

The rover could also carry a Viking-type passive seismometer. The value of this experiment would be strongly enhanced if the traverse took place while two or more previously landed seismometers were still operating at fixed sites on Mars.

6. Life detection. (Optional) A Mars rover could carry Viking-type biology instruments, and a negative or blank result from Viking might dictate this choice. However, the roving mission presents an opportunity to make hundreds or thousands of measurements, instead of the few planned for Viking, so that the consumption of reagents or sweep gases, intercontamination of successive samples, and control of metabolic products become significant problems. The very natural desire to wait for Viking results before starting design of a traverse biology package may prove to be a factor controlling the rover's development schedule.

II. Mission Description

Roving missions divide naturally into two classes: those in which the main or only scientific mission is that of the rover and those in which the rover is essentially a small adjunct to a stationary lander. In either case, advance orbital mapping and weather observation of the intended traverse region are highly desirable but not mandatory.

Rovers corresponding to these two mission classes have been studied (Refs. 9–12). A typical traverse, assuming the roving mission to be prime and the lander (if any) to carry only rudimentary scientific instrumentation, could be as follows:

After landing on Mars, the rover would first be located and its orientation determined by reference to landmarks and celestial objects such as Sun and Earth. Then, after any required engineering checkout, it would be commanded to make *in situ* measurements within and outside the area disturbed by landing rocket jets. Because of the long communication range and limited periods of mutual view, command sessions would be brief and much of the rover's activity would be in response to programs stored on board. Closed-loop commanding with human operators in the loop, as used for the Russian Lunokhods (Ref. 13), is probably out of the question on Mars.

After the local survey, the rover would strike out across country, stopping for orientation, location, path decisions, and new command inputs at increasing intervals as operating confidence increased. Initial progress would be very

Fig. 1. Mars rover representative surface traverses

slow, perhaps only tens of meters per day, but the average traverse speed could later rise to some kilometers per day. Night travel is questionable. Imaging and the other scientific experiments would be performed at selected stops, and the future path and experiment sequences would be modified by command. Total traverse distance and time could be several hundred km and about one year, respectively. The scientific operations would be adaptive, but only to the extent and at the rate permitted by the long communications distance and the rover's limited experimental repertoire. Figure 1 shows traverses that might be planned to investigate the variations of Martian geology and environment from region to region. One mission ending on the North polar cap is shown.

III. Spacecraft Characteristics

Two classes of Mars rovers are possible based on Viking techniques. Both are described here as feasible alternatives. Either would provide a major augmentation of surface-exploration potential relative to a fixed lander.

The first kind of rover would be a large machine which would utilize most of the Viking-type landed weight capability (Fig. 2, Refs. 9 and 14). This mission could use launch, transit, and entry-aerodecelerator systems, terminal-descent rockets and radars derived from Viking-type systems. Postlanding subsystems would have to be repackaged, redesigned, or new. This rover could perform the long-range, long-duration mission described in Section II.

This machine would have a mass of about 550 kg, with an instrument payload capacity near 70 kg and power available for experiments and data transmission of about 20 watts while moving and 200 watts or more while stopped. It would have high mobility (surmounting obstacles of about 1 meter) and could traverse up to several kilometers per day for a year or more on Mars.

The second feasible kind of rover based on Viking is a small vehicle carried on and launched from the Viking lander (Fig. 3, Ref. 11). It could carry a Viking panoramic fascimile camera and a limited *in situ* analysis package such as a combined alpha backscattering and X-ray analyzer. Traversing at a rate of about 100 meters per day, it could explore outward from the lander for some tens of kilometers, giving data similar to those produced by the Soviet Lunokhod Rovers (Ref. 13, 15, 16).

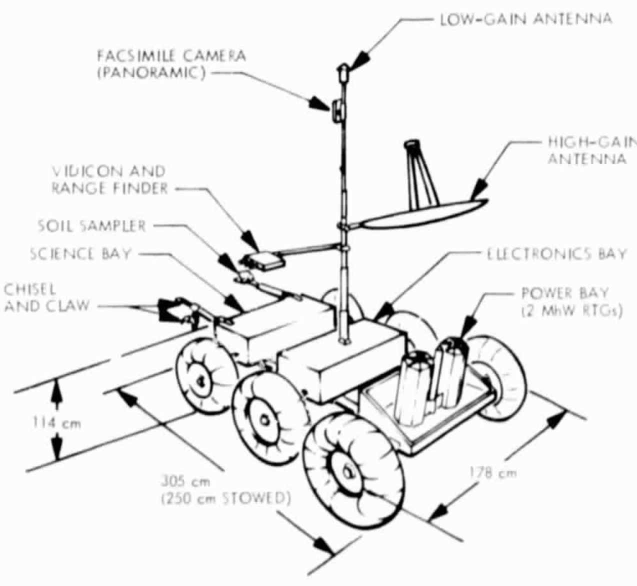


Fig. 2. Large Mars rover configuration

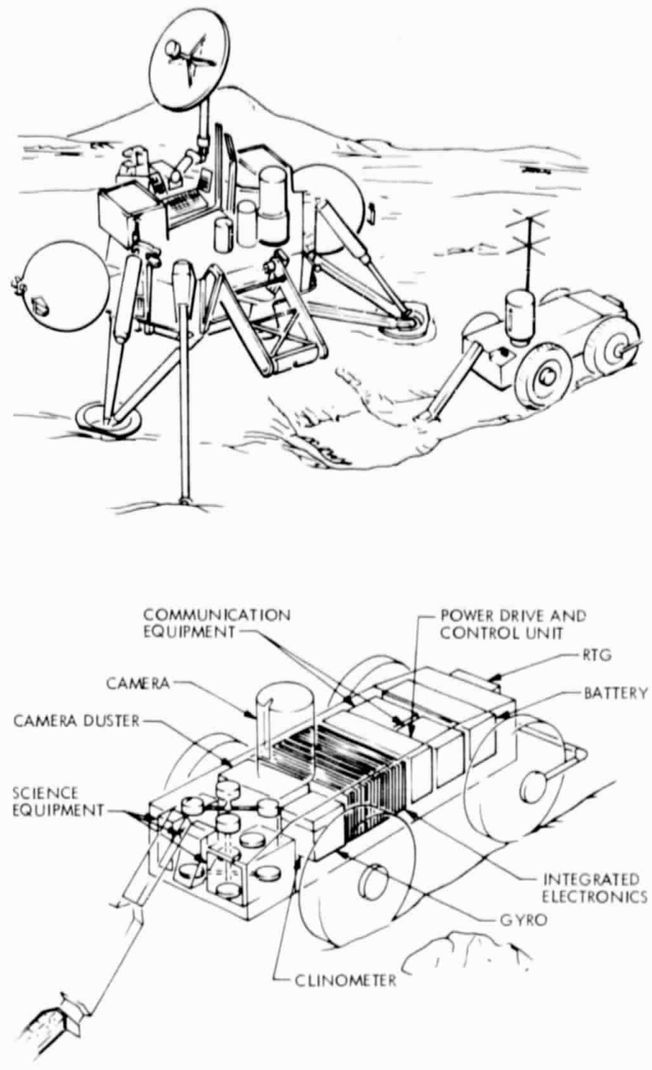


Fig. 3. Small Mars rover, with lander

Such a Mars rover would have a mass of about 100 kg, an instrument payload of 10–15 kg, and a limited electrical power supply allowing perhaps 20 watts for experiments and data transmission, and that only when stationary. Another alternative would be to include a mobility system on the Viking lander. The entire lander system would be commanded to traverse the surface.

IV. Mission Options

Either of the two rovers described above could be used in several different ways. For example, the large rover, if designed for a long enough lifetime, might be used ultimately to bring samples in to a landed sample-return spacecraft, which would then bring them back to Earth. The small rover could, instead of emphasizing *in situ* measurements along a one-way traverse, be equipped with a sample-acquisition tool and used to bring samples to the lander for analysis. Such a traverse is illustrated in Fig. 4, taken from Ref. 11. This would confine the exploration much more closely to the landing site in exchange for a more thorough investigation of the collected samples.

Some options beyond the performance limits represented by these two rovers have been studied. A very small, tethered rover could slightly extend Viking's sample-acquisition range. At the larger size, higher degrees of automation have been studied, and it is clear that a more autonomous rover could safely cover much more ground and do many more experiments in a given time. However, apart from the cost of developing these capabilities, there remains the question whether or not such a highly automated traverse is compatible with the way early, exploratory science is done. Given the strange environment and the strong component of ad hoc reconnaissance in the mission, the slow progress of a rather unintelligent but responsive and versatile rover may be entirely appropriate.

V. Program Assessment

Because of the substantial amount of new development required for the large rover, it would be programmatically risky to plan this mission for 1979 or 1981; in any event, to do so would require major changes in other established NASA programs. Therefore, 1984 is considered the earliest launch date for this class of Mars rover.

Studies directed toward the quantitative definition of the science objectives and payload, mission, and vehicle characteristics are needed if this type of mission is warranted in an overall Mars exploration program. However, to provide program planning data, funding estimates are provided for a rover with the following instruments:

(1) Sampler boom and head.

(2) Panoramic facimile cameras (2).

(3) Close-up imaging (TV).

(4) Chemical composition (alpha/X-ray fluorescence).

(5) Mineralogy (Close-up TV).

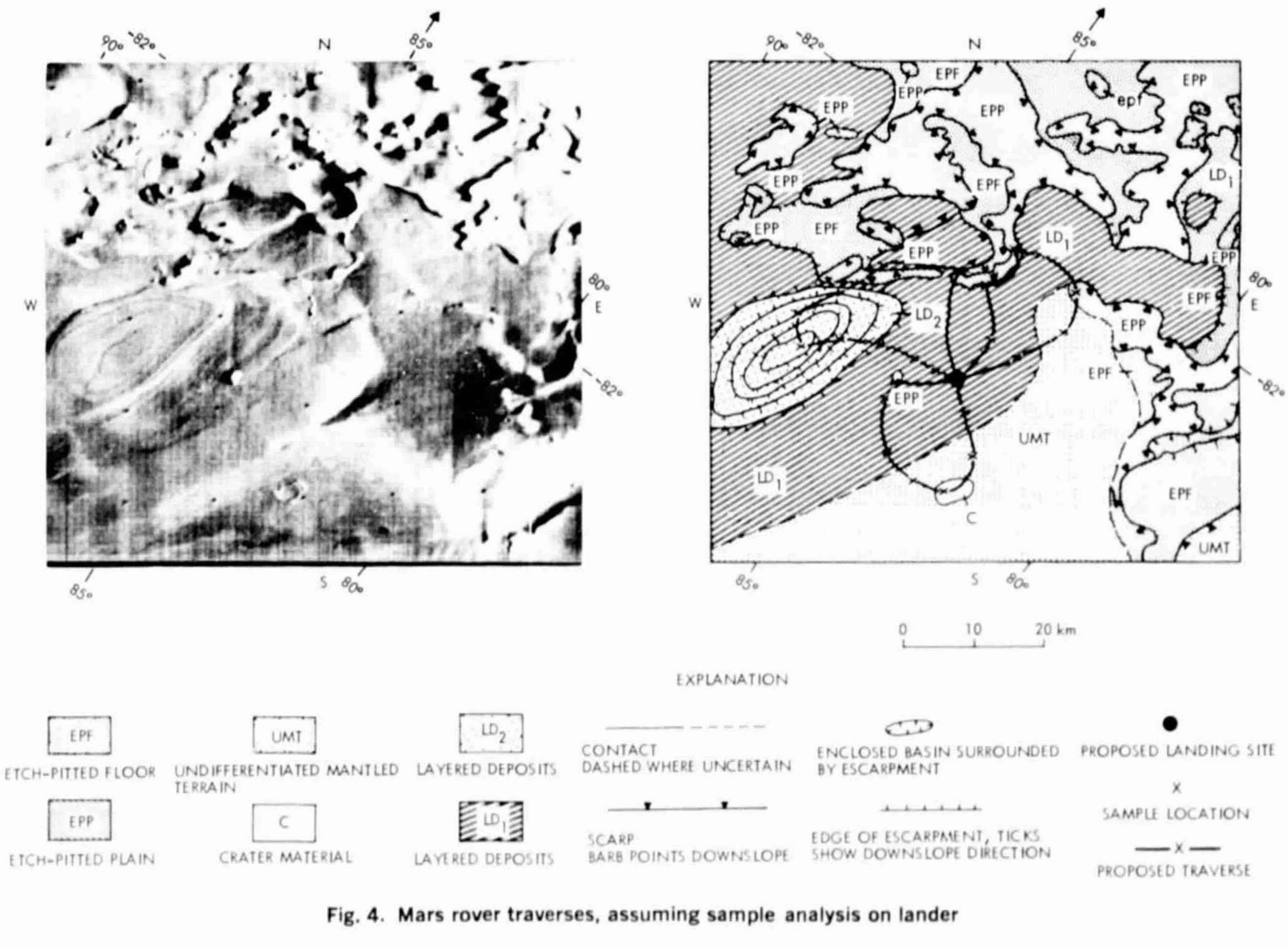


Fig. 4. Mars rover traverses, assuming sample analysis on lander

(6) Volatiles detection (humidity detector, gas chromatograph).

(7) Geophysical measurements (seismometry, dielectric constant by radar sounding, etc.).

Total program cost for this mission is estimated to be $550 million (FY75). Approximately $300 million of this total is required for the rover.

The incremental cost of adding the small rover mission to a basic Viking mission would be $25 to $60 million, depending on the chosen levels of experiment performance, technical risk, quarantine assurance, and schedule. The cost of the Viking carrier would be several times the cost of the roving mission. However, in view of the high cost of delivering either rover to Mars, the later schedule and higher cost of the large rover may prove acceptable in exchange for its much greater capability.

The cost study was based on the following assumptions:

(1) Launch vehicle and DSN-support costs excluded.

(2) Single flight spacecraft.

The project cost breakdown in millions of dollars (FY75) is as follows:

Rover science	70
Rover system	200
Spacecraft and landing system	230
Contingency	50
Total	550

Funding requirements as a function of time are given in Table 1.

Table 1. Mission funding spread

FY75 dollars (millions)	79	80	81	82	83	84	85	86	87	Total
Fiscal year	16.4	71.5	110.0	143.0	99.0	66.0	22.0	16.6	5.5	550.0

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