Unmanned Surface Traverses of Mars and Moon: Science Objectives, Payloads, Operations

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Theme

THIS synoptic and the full paper provide an initial evaluation of science aspects of a long traverse mission across the surface of Mars or the Moon, using a remotely-controlled roving vehicle. No mission constraints were imposed, and no attempt made to define minimum missions.

Contents

The over-all goals of a long traverse mission on Mars are considered to be determination of: distribution of surface composition; internal structure and thermal regime of the planet; nature of the major surface features and of the processes that formed them; atmospheric regime; environmental conditions pertinent to the development of life; past or present existence of life; and, if life is found, the nature of that life. Life on Mars may exist only in limited areas where conditions are most favorable. Thus, whether or not earlier lander missions find evidence of life, an important reason for sending a rover to Mars may be to search for places where life may exist. On the moon, determination of surface composition and surface features would be of primary interest, with some attention to internal structure and thermal regime.

A rover forms only one element of a desirable Mars traverse mission. Other elements of scientific importance should include a Mars orbiter, a science package at the landing site, science packages emplaced by the rover away from the landing site, and possibly instruments for measurements during atmospheric entry and descent. (The Mars orbiter is discussed in Ref. 1.) These elements appear less important for a lunar traverse mission. Return to Earth of samples gathered by the rover is simpler for the lunar mission, and is considered.

Among the geological and geophysical properties to be directly measured or observed are: geomorphic features, rock units, structural elements, and rock texture; mineralogic and elemental composition and volatiles; chemical, physical, optical, and mechanical properties of soils and rocks; magnetic field and gravity.[2] On Mars, planetary rotation and seismicity are appropriate observables. Meteorological properties include atmospheric composition, pressure, temperature, wind, suspended solids, and sunlight at the surface. Biological characteristics at Mars include both organic matter and life. If practical, the rover should also provide measurements and observations of isotopic composition, time of chemical differentiation, and fossils. Requirements for each of these measurements are given in Refs. 1 and 3.

For each planet, a family of 8–10 candidate rover science payloads is proposed to meet these requirements. They vary in weight, cost, development needed, and scientific specialization.

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The smallest lunar science payload, oriented to geophysics, includes only TV and facsimile cameras for terrain examination, gravimeter, magnetometer, and electromagnetic sounder. A less specialized small lunar payload (for a mission without sample return) adds a TV camera for rock specimen examination, general-purpose manipulator with tools, crusher, sample buffer storage, and X-ray emission spectrometer, and omits the sounder. Larger lunar payloads are also suggested.

The smallest Mars payload, specialized toward geological science, includes a TV camera, general purpose manipulator arm, crusher and siever, X-ray diffractometer/spectrometer, gravimeter, magnetometer, meteorological instruments, and radio transponder. Another Mars payload includes, for imaging, two TV and two facsimile cameras, laser range finder, and a microscope. For sample handling, it includes a general-purpose manipulator with interchangeable tools, a crusher and siever, viewing stage, and sample buffer storage. Analytical instruments in this payload are an X-ray diffractometer/spectrometer, a gas chromatograph/mass spectrometer/differential thermal analyzer, a water detector, a pyrolysis/gas reaction chamber, a soil/gas exchange chamber, gas handling equipment, a labelled-compound radiation detector, ten culture chambers with a culture-medium dispenser, and a liquid-suspension nephelometer. Geophysical instruments aboard are a gravimeter and a magnetometer. A barometer, anemometer/wind direction indicator, atmospheric thermal sensor, hygrometer, UV photometer and radio transponder are also carried. The geophysical instruments, soil-gas exchange chamber, and X-ray spectrometer would be deployed to the surface for measurements and then retrieved by the rover. In addition, this payload would include a permanently emplaceable science package, to be left behind as the rover proceeds, which contains a seismometer, a magnetometer, weather instruments, a UV photometer, and a radio transponder.

The characteristics of the individual instruments, as well as the science tasks and operational functions associated with the measurements, are given in Refs. 1 and 3. Science payload weights range from 35 to almost 300 kg, including instruments in emplaced science stations. The average payload power (including diversity factors) during science operations (vehicle at rest) ranges from 36 to 139 w. Science power during vehicle motion (4–61 w) is assumed limited to analytical equipment and the electromagnetic sounder; camera or range-finder power during vehicle motion is assumed chargeable to guidance, since there is no science requirement for operation of these instruments during motion.

A wide-angle TV picture with the selected characteristics includes 6×10^6 bits; a narrow-angle TV picture, 1×10^7 bits; a facsimile panorama, 3.9×10^7 bits. For Mars, a TV data rate of 128 kbits/sec was assumed, based on a preliminary look at the frame time required. The assumed Mars–Earth transmission channel has a capacity of 32 kbits/sec of science imaging data (either 32 kbits/sec of raw data or 16 kbits/sec of data compressed 2:1), continuously available except during rover motion. A timeline worked out for activities at a science site (item 3 below) includes 120 science pictures containing 1.1×10^9 bits. The peak data storage in this sequence is about 10^8 bits pre-compressed 2:1.

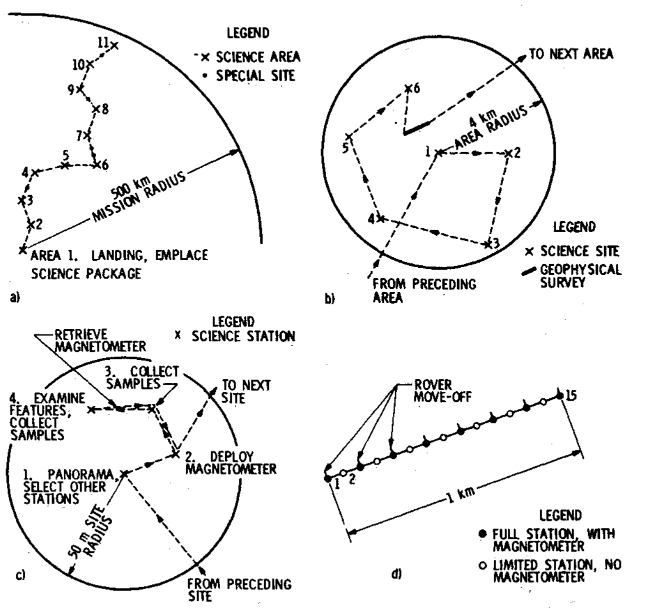

Fig. 1 Schematic of elements of science profile: a) mission traverse, b) science area, c) science site, and d) geophysical survey.

From the moon, the transmission channel is tentatively constrained to 0.5 Mbits/sec by limitations in digital ground data-handling equipment; a 2 Mbit/sec channel seems operationally desirable and could probably be provided. These rates would match the payload data rates, permitting transmission of science data in real time without storage on the rover.

For Mars, where the transmission delay-time is long (6 to 44 min round trip) and data rate limited, a high degree of internal control should be possible on the rover. This would include carrying out complex sequences involving imaging, manipulation, vehicle motion, chemical analysis, biological culturing, geophysical surveying, and meteorology.[4] The internal control capability of the rover should include using data obtained by the scientific instruments to change rover operating sequences and parameters. All motion and science sequences, telemetry content, and rover transmission sequences should be readily and quickly alterable by earth command.

For the moon, with a round-trip transmission delay of 2.5 sec, internal control of science operations is unnecessary; science decisions can be made on Earth. On both Mars and the moon, primary science operations are assumed to be constrained to periods of local daylight, but at night the rover should be able to analyze on-board samples, transmit data from deployed instruments, and do a limited amount of sampling.

A science profile is outlined for a Mars traverse mission lasting 1 Martian year and extending over a radius of 500 km from the landing site. The total (track) distance covered is taken to be 1000 km and the vehicle speed 0.25 km/hr. The profile breaks down as follows:

1) The rover will investigate the landing area and ten other science areas within 500 km of the landing (mission traverse, Fig. 1a). The science areas will ordinarily be chosen prior to the mission.

2) Within each science area, nominally 4 km in radius, measurements will, on the average, be made at six science sites and one geophysical survey (Fig. 1b). Science sites will ordinarily be selected on the basis of high-resolution imaging and other data obtained by Mars orbiters. Geophysical surveys will be selected on the basis of data obtained by Mars orbiters and the rover.

3) At each science site, the rover will stop at three or four science stations, on the average, within a 50-m radius, to take pictures, deploy instruments, and collect samples (Fig. 1c). The rover may move a few meters at each station. Science stations will generally be selected on the basis of rover observations at the site.

4) A geophysical survey will average about 1 km long and will consist of 8 to 15 geophysical stations (Fig. 1d). Geophysical stations will be selected on the basis of rover and orbiter observations. In many cases they may be spaced at fixed intervals along the survey line.

A preliminary timeline has been prepared for operations at a science site and on a geophysical survey; timelines for science areas and for the mission traverse were also derived. The contemplated operations at a Mars science site take at least 15 hr. Included in these 15 hr are 11 periods of waiting for inputs from humans as to selection of features and samples that appear to warrant more detailed examination. Each wait requires time for transmission of up to 8 frames of TV, two-way transit delay between Mars and Earth, and human science decision on Earth. These waiting periods pace the operation. Other science operations, such as a geophysical survey, should be possible in a completely automated mode without intervention from Earth, though intervention would be possible if it became necessary.

Measures to reduce the delay in the control loop between Mars and Earth and the number of times this loop is used are important in increasing the scientific return per day of operation. (Man-machine relations in the control of science operations are discussed in Ref. 4, motion control in Ref. 5). Science site operations are also highly sensitive to communications channel capacity and delay. Moreover, two or three ground stations will be needed for communication. The order in which the pictures are transmitted is considerably different from that in which they are taken; pictures needed for immediate operational decisions have a higher transmission priority than pictures which are taken for scientific analysis only. The system must accordingly be capable of storing many pictures at Mars and of transmitting them in any order as governed by immediate operational needs. Preferably the rover should be capable of full operation during the Martian night to increase its output of results per year.

The lunar science profile (for a mission lasting one Earth year) is broken down in the same fashion as the Martian. Intervals of waiting for decisions on Earth are greatly reduced and the number of pictures can be greatly increased. The vehicle speed and over-all track length can be increased (1.5 km/hr, 2000 km track), as can the number of science areas, sites, and geophysical surveys. (Note that Lunokhods 1 and 2 performed local investigations of an area, with track distances of a few tens of kilometers rather than long traverses covering many areas.[6,7] The planned missions are thus considerably more ambitious). Investigations on the moon can be more detailed than on Mars and time will be available for more targets of opportunity (such as the "special sites" of Fig. 1a). Operational problems will be considerably simpler than for the Mars mission. Thus, differences in the radio transmission times to Earth and in communications channel capacity lead to major contrasts between moon and Mars missions in control of the surface vehicle, in timeline, and in mission operations.

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