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MINI-ROVERS FOR MARS EXPLORATION

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ABSTRACT

Rovers are desirable for surface exploration because they allow sampling, and sample returns from several diverse locations on a planet's surface. Unfortunately, the rovers currently being examined for Mars exploration have several undesirable features. These rovers are quite massive (500kg to one ton), have very complicated operations, and are very expensive. This paper describes a possible alternative to using large rovers for exploring the surface of Mars. In this paper, the idea of mini-rovers is proposed. Mini-rovers weigh less than five kg, are trivial to control from the ground, and can do a more thorough survey of the terrain (per kilogram of mass) than can be obtained by large rovers. By redesigning the Mars sample return mission to accommodate the idea of mini-rovers and small spacecraft, considerable mass and cost savings can be achieved.

1. INTRODUCTION

The two major cost drivers in any spacecraft that has been flown have been mass and reliability. Mass is inherently expensive due to the energy costs for getting a spacecraft where it is going. Reliability has been approached either through subsystem redundancy (which increases mass) or major new technology developments combined with extensive testing (which drives cost directly). An alternative method for increasing reliability would be to have mission component redundancy; this again drives up mass and cost - but these can be brought back down if the components can be reduced in size, cost, and mass. For some types of mission, particularly robotic missions where the science payload is small or distributable, this may now be possible.

When the size of a mobile robot is reduced, most aspects of the robot improve or simplify. The power for the mobility system is greatly reduced. For most operations this makes solar power more practical. The mobility of the system may actually improve; in natural terrains, the fractal nature of the terrain combined with the reduced surface pressures allow greater freedom of movement.

Up until now, a major stumbling block in reducing the size of robots for planetary missions has been the combination of communications and intelligence. Communications does not scale well. Maintaining a sufficiently high data rate to control a robot from the Earth precludes reducing the size and power of the robot. To reduce communications, one can make the robot more autonomous. JPL projects in this vein (e.g., Pathfinder rover) have usually taken approaches that require several tens of MIPS of processing power onboard, which meant that the computation system was the power and mass driver. However, these are not the only possibilities.

Recent work in behavior control languages [Brooks86, 89], [Gat 90] has shown that robots can be controlled to perform useful unstructured tasks with relatively little computation and very small programs (a fraction of a MIP and a few K bytes of program). The resulting control programs allows a robot to operate almost completely autonomously. This again reduces the need for communications and computation. With communications and computation greatly reduced, the entire size of the robot can be reduced as well. A smaller lighter robot, requires less fuel to get it to its destination, can more easily be landed on a planetary surface (parachutes and impact limiters become feasible), and can be sent in greater numbers for comparable costs than can larger robots [Miller89a, 89b].

By carefully thinking out the robot's tasks, it is possible that small robots can be made to accomplish most of what larger robot rover can. The behavior control languages used in mini-robots are more than adequate for having a rover avoid obstacles, rendezvous with the ascent vehicle, and collect samples. Careful selection of sensors and placement of radio beacons will allow such a robot to carry out other science tasks. Things that are difficult for this type of robot to accomplish are map-making and carrying massive payloads. However, map-making is mostly used to guide a robot, and there are alternatives. Massive payload can often be distributed among several small robots.

A behavior controlled robot has many of the characteristics of an insect. It has a robust set of simple behaviors that will allow it to handle most situations.Such a robot does not maintain a detailed world model - it therefore cannot readily determine when something unexpected has occurred. Like an insect, in situations that fall outside of its design parameters it will often fail. But also like an insect, such a robot can be small and inexpensive enough so as to have replacement robots waiting to take over.

2. MINI-ROVER MISSION SCENARIO

Below is a possible mission scenario for a multi-sample site, sample return mission to Mars that I believe could accomplish the major scientific and manned precursor goals of a full-up MRSR (Mars Rover Sample Return) mission at a substantially lower cost. The central feature in this mission scenario is the use of 100 mini-rovers (each < 5kg) rather than a single one ton rover. The use of the mini-rovers also effects the landers, orbiter, and Mars ascent vehicles. The Mars-Earth return vehicle would probably remain more or less unchanged, as would the launch system - though it may now be possible to go to a smaller launch vehicle.

Mission Elements

The major mission elements are a relay communications orbiter (MCO) placed in Mars-synchronous orbit, 100 mini-rovers and their landing pods, a Mars ascent vehicle (MAV) and its landing pod, and a Mars-Earth sample return vehicle (ERV). Every five rovers form a group that has an associated landing pod which deploys a small parachute and then hard lands on the Martian surface. An airbag or crushable front-end is used to decelerate the rovers upon impact. Two Mars ascent vehicles, each with an associated landing pod, use similar methods to land on the Martian surface. The MAVs also has an inflatable belt that can be used to reorient them into a launch orientation. The MAVs contain a non-directional radio beacon (NDB). The MAVs use a two-stage launch sequence from Mars. The first stage boosts the MAV to near orbital velocity. The second burn occurs at apoapse, and puts the return capsule into low Mars orbit. The return capsule has a solar powered docking beacon and is spherical in shape. The capsule is not stabilized, but its spherical shape (and central CG) will allow simple docking with the Earth return vehicle.

Mission Scenario

1) The MCO is placed in Mars synchronous orbit at the longitude of the landing site.
2) The ERV is placed in a Mars rendezvous orbit.
3) The MAVs and rover groups are landed on the surface with the MAVs in the approximate center of the dispersion of rovers. The rovers form a buckshot pattern covering approximately 100km diameter spread (see Figure 1). At the East Mangala site this would cover several different types of terrain.
4) The primary MAVs' NDB is deployed and the rovers home to that.
5) Each rover gathers one or two samples near its landing site, recording the relevant information. The group of rovers employ their different science instruments on each of the sample areas.
6) At the start of each day the rovers progress towards the primary MAV.

7) Each day the rovers find a piece of clear local high ground and take a stereo pair, and other science data.
8) Before sundown, the rovers relay their data to the MCO.
9) The MCO relays the new data to Earth.
10) As each rover reaches the MAV, it transfers the sample to the MAV, does an about face and starts its extended mission.
11) When the MAV is ready to ascend, it leaves the NDB so that the rovers will continue to have orientation information.
12) The MAV ascends. The ERV docks, retrieves the sample canister, and returns it to Earth.

3. MASS ANALYSIS

The rovers small size allows them to be relatively hard landed on the surface. It also makes them much more power efficient. The rovers use local radio communications, to minimize the power expenditure. The rovers are solar powered during the day. It may also be possible to use the temperature differential between the top soil and the night air to power the rovers at night. The only commands that need be given to the rover from the ground would be to drop its current sample and get another one from its current location. The rovers could have a low-power slow speed vise to crack rock and get fresh samples. Each rover would return a few grams of sample (see Figure 2).

The MAVs could be very small. Assuming 200g of samples (4g each from 50% of the rovers), it should be possible to design a total return capsule to mass approximately 1.5kg. Remember, the capsule is a totally passive system with a small solar powered radio beacon. The capsule has no active thermal control, but is heavily insulated. The capsule is either in Mars normal conditions, when it is on the surface, or part of the ERV. The ERV has less

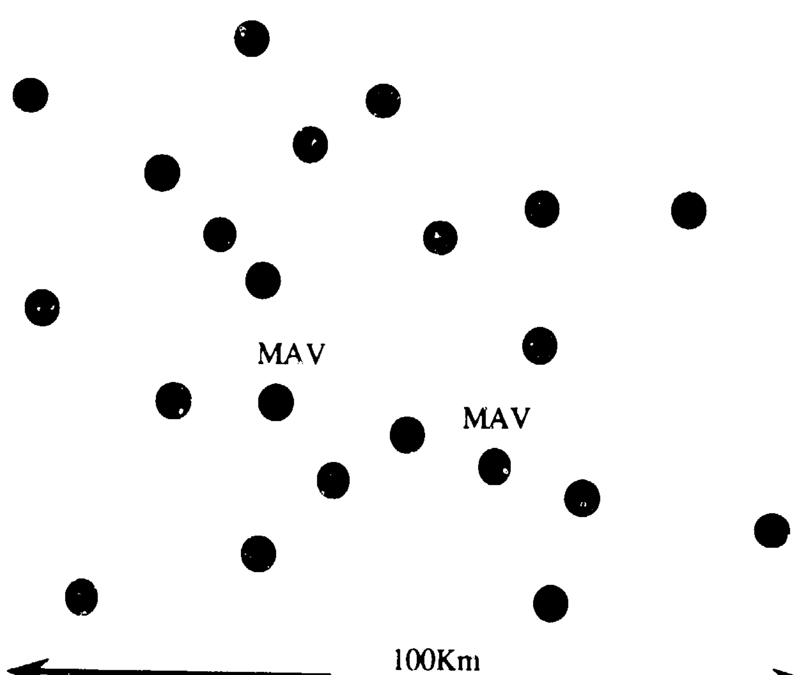

Figure 1. Distribution of rover CSAD capsules and ascent vehicles

stringent mass constraints and could therefore exhibit active thermal control on the capsule. The capsule would be on its own, in orbit, only for a short time.

Low Mars orbit requires a velocity of 3.6km/sec. 280second impulse is typical for the type of low-maintenance fuel that might be used on a MAV. Such a fuel has an exhaust velocity of approximately of 2.7km/sec. This leads to a mass ratio of 3.79 between fuel and the remainder of the MAV to get it into orbit. Assuming the rocket casing requires a mass of approximately 10% of the propellant weight, and that a short term (missile style) gyro and gas reaction jet system would mass approximately 2.5kg. The masses on the MAV have the following breakdown:

Sample return capsule	1.5kg
Guidance & Control	2.5kg
Rocket casing	3.0kg
Rocket fuel	30.0kg
TOTAL MASS	37kg

The MCO acts as a relay between the MAV and the Earth. The pointing accuracy needed for the orbiter is the minimum needed for communications with Earth. No imaging is needed for this mission. Viking and MO data will suffice for landing site selection. The Areo-stationary Direct-relay Communications Orbiter is one possible model for the MCO. With its reaction control system fully loaded it masses approximately 400kg.

The Earth return vehicle must return the 1.5kg sample capsule and will (from D.Bernard) also require a guidance system massing approximately 60kg. Approximately 2.3km/sec deltaV is required for moving from Mars orbit into Earth insertion. This leads to a mass ratio of 2.35 when using the same fuel as used in the MAV. For an Earth orbit rendezvous, it should be possible to build an Earth return vehicle to bring back the 1.5kg sample canister where the entire return vehicle masses under 600kg. This includes a large margin for performing the Mars rendezvous with the return capsule.

The *Capsule System Advanced Development System*, developed in 1967 to survivably land a science package on the surface of Mars, used a mass ratio of approximately 1.6 between the support hardware (e.g., aeroshell, parachute, and shock absorbers, etc) and the payload that was landed in working condition. The CSAD capsule was derived from the Ranger landing capsule [Ranger63] which had a slightly higher mass ratio (approximately 2:1). CSAD was designed for

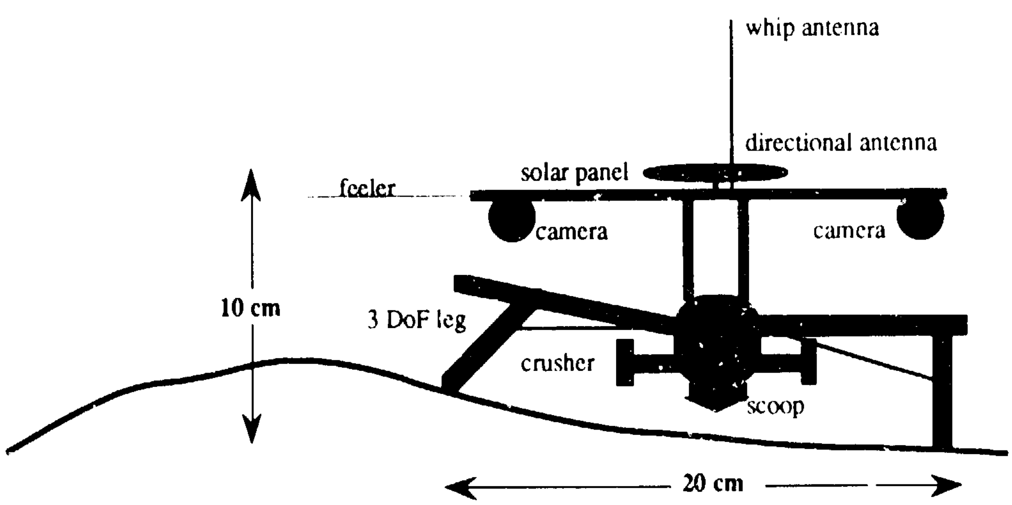

Figure 2. Front view of a Mini-Rover

landing payloads in the 30-50kg range. The MAVs and the mini-rovers mass approximately 580kg. Using the 1.6:1 ratio for the CSAD capsule, the capsules would mass approximately 928kg giving a combined mass to be sent into Mars terminal descent of 1508kg. 400kg is placed in Mars-synchronous orbit (the MCO), and 600kg are in a low-Mars rendezvous orbit (the ERV). The mission described above would require a total of about 2.5 metric tons to be flown into Mars space.

4. ADVANTAGES OF USING MINI-ROVERS

Some of the advantages of this scenario over the traditional MRSR scenario are:

1) Very high redundancy: While it is almost certain that some rovers will not survive to deposit their samples, many will.
2) Larger scientific coverage: Approximately 2500km will be traversed in the scenario outlined above (assuming a 50% rover survival rate). More varieties of terrain will be covered. More varied samples can be gathered.
3) This mission should be much cheaper. The technology is simpler. There is no pin-point landing required, there is no imaging orbiter required, there is no nuclear power technology needed, the computer technology needed already exists and is already space qualified, as is the pointing technology, landing technology, and the communications technology; the amount of mass landed on the surface is also greatly reduced.
4) This mission could be brought together in a relatively short time, perhaps for a '94 launch. This means that samples could be back in time to provide landing direction and instrumentation analysis clues for a full-up rover mission during a later opportunity
5) The rover technology for this mission is relatively cheap and easy to test and demonstrate.

5. CONCLUSIONS

The pieces needed to make use of mini-rovers for planetary missions are all under intense development with the exception of the robots themselves. Lightweight, low power cameras [Ravine89], and science instruments [Murphy81, Manning77] have already been developed. Power systems (both solar and RTG) that mass a few hundred grams and deliver a few watts, have been developed [JPL88]. The same is true of communications systems that can broadcast to the DSN at 55bits per second at three AU, and masses under a kilogram, drawing less than four watts [JPL88].

Mini-rovers offer a potentially cost-effective way of exploring Mars and other planetary surfaces. The use of small rovers has many advantages and few disadvantages over using large rovers. By taking advantage of scaling laws and currently available technology, a micro-rover sample return mission is doable in the very near future.

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