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Long-Range Rovers for Mars Exploration and Sample Return

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ABSTRACT

This paper discusses long-range rovers to be flown as part of NASA's newly reformulated Mars Exploration Program (MEP). These rovers are currently scheduled for launch first in 2007 as part of a joint science and technology mission, and then again in 2011 as part of a planned Mars Sample Return (MSR) mission. These rovers are characterized by substantially longer range capability than their predecessors in the 1997 Mars Pathfinder and 2003 Mars Exploration Rover (MER) missions. Topics addressed in this paper include the rover mission objectives, key design features, and technologies.

INTRODUCTION

NASA is leading a multinational program to explore above, below, and on the surface of Mars. A new architecture for the Mars Exploration Program has recently been announced [1], and it incorporates a number of missions through the rest of this decade and into the next. Among those missions are ambitious plans to land rovers on the surface of Mars, with several purposes: (1) perform scientific explorations of the surface; (2) demonstrate critical technologies for collection, caching, and return of samples to Earth; (3) evaluate the suitability of the planet for potential manned missions.

In order to meet these objectives, the rovers under consideration for the Smart Lander/Mobile Laboratory (SLML) and Mars Sample Return missions are substantially more capable and complex than the Mars Pathfinder Sojourner rover and even the twin Mars Exploration Rovers [2] to be flown in 2003 (Figure 1). These rovers will have large payload capability (in excess of 100 kg), long life (one year or more), and long range (in the tens or hundreds of kilometers). The long range aspect is particularly significant. With advanced entry, descent, and landing (EDL) technologies to reduce the landing error ellipse and ensure safe landing in an uncertain terrain, combined with long-range multi-site roving capabilities, these rovers will--for the first time--have the ability to perform "go to" missions to locations designated in advance by project scientists.

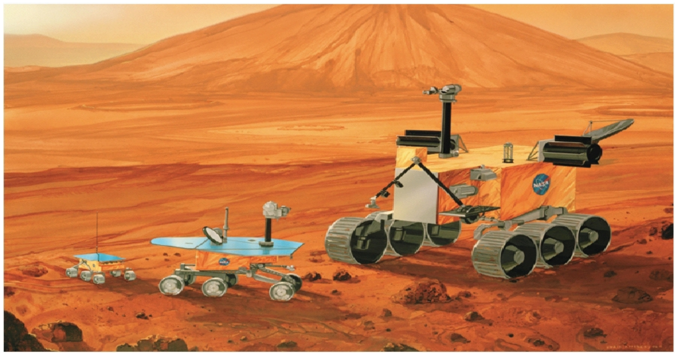

Figure 1: Rover Size Comparison (Mars Pathfinder, Mars Exploration Rover, '07 Smart Lander/Mobile Laboratory)

The first of these rovers, the Smart Lander/Mobile Laboratory (SLML) is scheduled for launch in 2007. The current program baseline is to use this mission as a joint science and technology mission that will contribute directly toward sample return missions planned for the turn of the decade. These sample return missions may involve a rover of almost identical architecture to the 2007 rover, except for the need to cache samples and support their delivery into orbit for subsequent return to Earth.

Three broad "generations" of Mars landed elements may be envisioned, with the first generation being represented by the class of rovers including the Mars Pathfinder Sojourner Rover and the MEP rover, the second generation being represented by the SLML and MSR rovers, and the third generation represented by a future class of large, very-high-precision landing rover. Table 1 summarizes the key features of these systems.

This paper is divided into several sections, describing the key elements for both the SLML and MSR rovers. These sections discuss objectives, design features, and major technologies for the key elements. It is anticipated that further refinements to the rover designs may be reported at future meetings.

Table 1:Rover Capabilities by Generation

	First Generation	Second Generation	Third Generation
Examples	Mars Pathfinder Mars Exploration Rover	Smart Lander/Mobile Laboratory Mars Sample Return	Next Decade
Landing Error (Major Axis)	100-300 km	3-6 km	10-100 m
Science Payload	25-70 kg	Up to 300 kg	500+ kg
Lifetime	90 days	One year	2-5 years
Roving Capability	0-1 km	1-10 km	10-100 km

HIGH ACCURACY DELIVERY

The first generation of Mars rovers used a direct atmospheric entry from a hyperbolic trajectory, with no active control of entry body lift for guidance. This resulted in a landing error major axis of well above 100 km. (Note: No rover currently envisioned has the range to rove out of an error ellipse of this size.) The second generation of lander/rover is designed to reduce the landing error major axis by a order of magnitude or more, to less than 10 km.

The precision delivery begins with the navigation prior to entry interface. Earlier systems used radiometric navigation only, which gives a relatively large error contribution. Second generation systems will incorporate optical navigation for more precise location knowledge prior to entry interface.

Once atmospheric entry interface is achieved, the vehicle can take advantage of a non-zero L/D to control cross-range and down-range target position. While earlier systems had an effective L/D of 0, the second generation lander will have an L/D of approximately 0.25 or greater.

First generation systems use rocket thrust to reduce the descent rate prior to parachute cutaway and cushioned landing with airbags. The propulsive thrust is not used to guide the touchdown point position. Second generation systems will take a different approach. After an unguided period when being slowed by parachute, the second-generation lander/rover uses a targeted powered descent which offers touchdown location repositioning for both scientific and hazard-avoidance purposes (Figure 2).

HIGH MASS DELIVERY

The first generation of Mars rovers used a single stage parachute system for slowing the vehicle in the lower atmosphere. While providing for a more simple system, the single-stage parachute system limits the amount of mass that can be brought to the surface.

The key design parameter for a parachute system is the dynamic pressure limit, in units of force divided by area. This dynamic pressure limit can be directly correlated to a particular opening altitude and entry vehicle ballistic coefficient, which is proportional to mass and inversely proportional to drag coefficient and cross-sectional area. Cross-sectional area is limited by launch vehicle fairing diameter and the drag coefficient is set by the shape of the vehicle. Therefore, the maximum ballistic coefficient capability for a particular parachute design will directly affect the amount of landed mass to the surface.

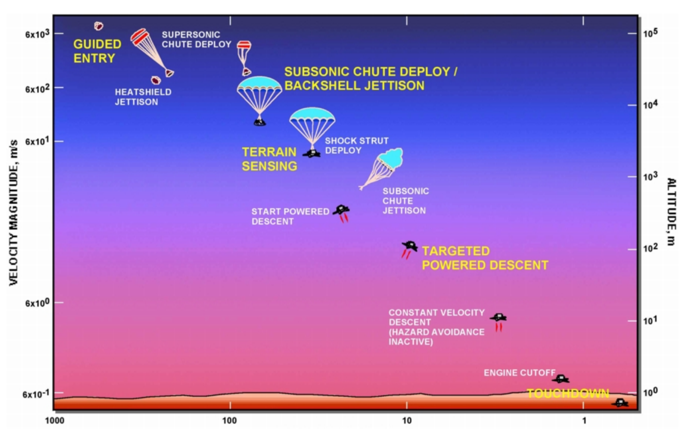

Figure 2: Second Generation EDL

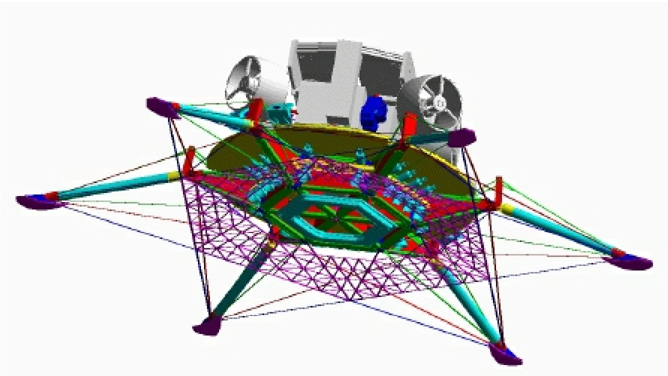

Figure 3: Pallet Lander Concept

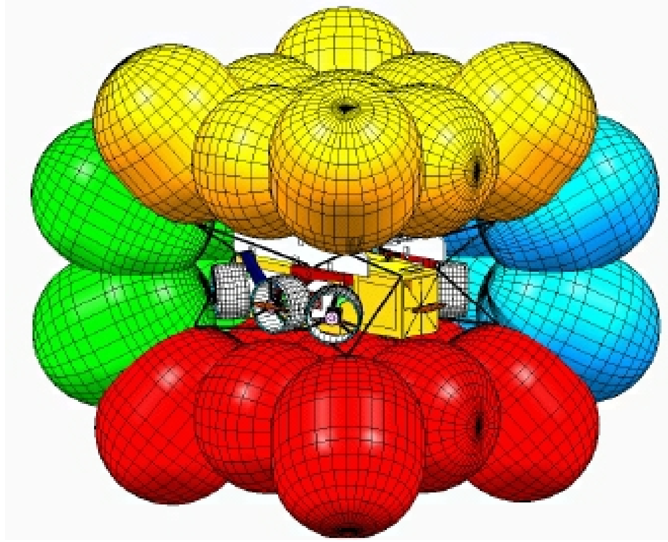

Figure 4: Airbag Lander Concept

The second generation rovers are envisioned to use a two-stage parachute system with a Viking Lander-class M2.2 supersonic parachute for deployment at approximately 100,000 meters altitude and a subsonic parachute to be deployed at approximately 10,000 meters altitude. This combination enables landed masses on the order of 2000 kg, as opposed to the MER landed mass of approximately 500 kg.

SAFE LANDING

The addition of active touchdown point control and landing system robustness is expected to significantly improve the odds of a successful landing in a selected landing area, and in the limit can make possible the selection of somewhat more hazardous terrain if scientific objectives favor such a choice.

The first area of emphasis is to actively control the touchdown point. First generation systems do not attempt to control the touchdown point, as the airbag landing system will cause a number of bounces that will displace the landed system many meters from its touchdown point. The second generation systems will perform a powered descent to touchdown, using hazard detection sensors (LIDAR, optical, etc.) and guidance algorithms to avoid obstacles.

The lander will also be ruggedized to accommodate up to a 0.5m diameter rock and a 30 degree slope. Several concepts for protecting the lander are under consideration. Figure 3 shows a pallet-style lander concept, where the pallet absorbs the landing shock while also protecting the rover from obstacles. Figure 4 shows and airbag lander concept where airbags surround the rover.

Testing is underway on several promising concepts. A 3/8 scale model has been constructed for drop tests in a tower facility at JPL. The drop tests (Figure 5) will determine the viability of various pallet concepts under controlled obstacle size and slope conditions. If an airbag system is used, it may not take the geometrically self-righting tetrahedral form used for Pathfinder and MER. In this case, some means of self-righting must be incorporated. Figure 6 shows a concept where shaped airbags are inflated after landing. These and other tests are being performed to help define the configuration of the SLML and MSR rovers.

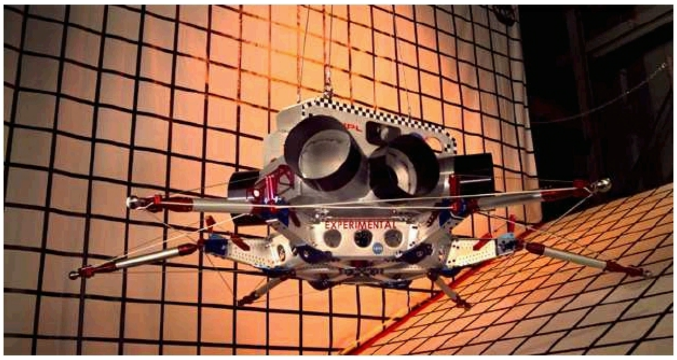

Figure 5: Lander Pallet Drop Test Mode

Figure 6: Airbag Self-Righting Test Article

"GO-TO" MOBILITY

For first generation systems, the landing error ellipse is on the order of 100-300 km, and the rover range is less than 1 km. As discussed above, the second generation EDL system is being developed to give approximately an order of magnitude improvement in landing accuracy. By giving the rover a range of 10 km or more, it is possible for the first time to identify a specific location or region and have reasonable assurance that the rover will be able to visit it.

An example is shown in Figure 7. The crater in the Elysium Planitia region exhibits features similar to the "gullies" found in recent studies by the Mars Orbital Camera (MOC). It is 10 km in diameter, with steep sides on both the outside of the crater, which would be difficult for a rover to summit. A first generation EDL system would not be able to guarantee a landing in the crater, but a second generation EDL system can be targeted within a landing error major axis of 10 km, enabling the inside of this crater to be targeted for exploration.

The rover range capability is a significant factor in a "go-to" scenario. With a landing error major axis of 10 km, the rover must have at least 10 km of range to ensure a visit to any point in the landing error ellipse. 10 km rover range is an order of magnitude greater than the state of the art defined by MER. While improvements in mechanisms such as drive motors and wheels will be necessary, the most significant required advances are in on-board autonomy and remote control capability. Mars Pathfinder required substantial planning to perform even short traverses, and the on-board autonomy was limited to simple rover self-protection. Second generation rovers will require self-localization, self-safing, and autonomous navigation capability to perform lengthy traverses while out of contact with ground controllers. These capabilities are being refined for flight application under the Mars Technology Program, with specific milestones to support the 2007 mission.

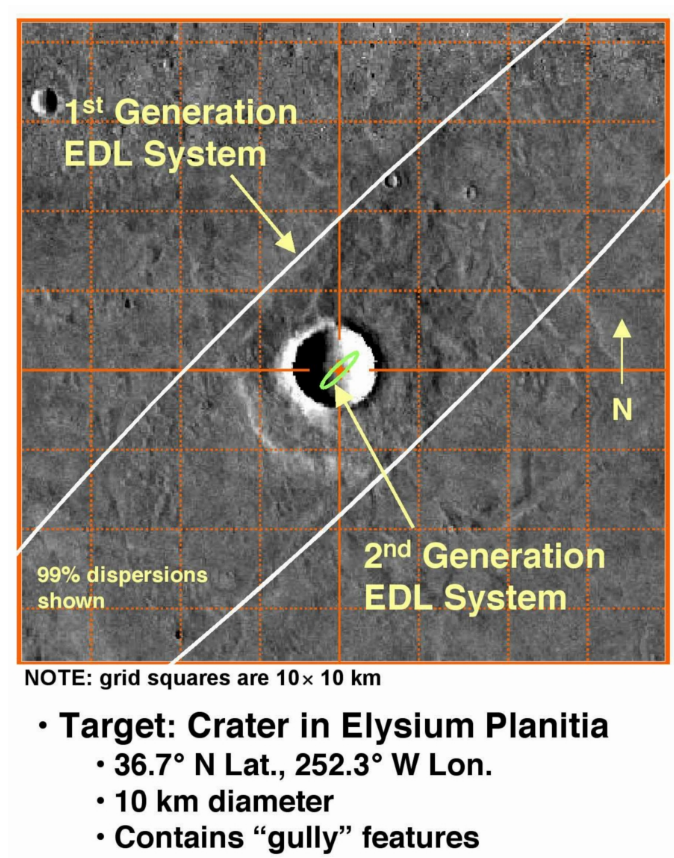

Figure 7: Example "Go-To"Target

LONG LIFE

First-generation rovers have relatively short lives (90-180 days), primarily due to dust accumulation on solar arrays and thermal cycling effects on rover components. Second-generation rovers seek to extend rover lifetime beyond 180 days.

The power system is a direct driver on lifetime. Two types of power systems are under consideration—solar and radioisotope. Solar power systems for second generation rovers would use higher-efficiency cells and higher energy-density batteries to significantly extend the power density levels in comparison to first-generation systems. Also under development are dust-mitigation systems to counter the approximately 0.2%/day reduction in array power output seen by the Mars Pathfinder rover.

Radioisotope power systems (RPS) may enable mission durations of one year or more. Furthermore, RPS may permit missions to high latitudes where winter insolation is low. A commitment to use of RPS is pending a series of scientific, technical, and programmatic assessments to determine if mission objectives are enabled or enhanced by radioisotope power.

IN-SITU SCIENCE

Another characteristic of second-generation rovers is the capability to perform significant in-situ science. In the case of the SLML, a subsurface drilling capability is under consideration to provide a third dimension of exploration. It is considered technically feasible to drill to depths of 2m or greater with technologies available for the 2007 mission.

Sophisticated sample analysis instruments, such as one proposed by the Agenzia Spaziale Italiana (ASI), will enable chemical and geological analyses of a variety of surface and subsurface samples. In the case of SLML, in-situ science is a major mission objective. The MSR rover will retain a strong in-situ science capability to support sample selection and to extend on science return even after the Earth-return aspect of the mission is accomplished.

FEED-FORWARD TECHNOLOGY (SLML)

Each baselined mission in Mars Exploration Program has two major objectives: (1) to perform significant science and (2) to validate critical technologies for use in future missions. The SLML mission has a particularly strong feed-forward technology component, directed toward the MSR mission.

The first area of feed-forward technology emphasis is in the EDL system. The MSR rover is anticipated to be similar in scale to the SLML system, and the second-generation EDL capabilities demonstrated in the SLML mission will be directly applicable to MSR. The “go-to” mission concept described previously combines precision landing with long range to enable specific sites to be visited. The validation of this concept for in-situ science in the SLML mission is applicable for sample acquisition and follow-on in-situ science in the MSR mission. Figure 8 shows a rover mechanical testbed for SLML concepts, with expandability to support additional requirements associated with MSR.

Figure 8: Rover Mechanical Testbed

SAMPLE COLLECTION & CACHING (MSR)

The MSR mission builds upon the foundation established by the SLML mission and its predecessors. The MSR mission will involve selection, collection, and caching of samples, which will subsequently be transferred on a secure container for Earth return. The Centre National d’Etudes Spatiales (CNES) has proposed to provide a system for retrieving a sample from Mars orbit and return it to Earth.

Specific mission architectures for MSR are still being developed, but one leading concept involves a mobile rover which will visit several scientifically interesting sites to collect and cache samples, which will subsequently be loaded into an Orbital Sample (OS) container fro launch into Mars orbit by a Mars Ascent Vehicle (MAV).

Figure 9 shows a concept for a lander-based MAV, with the rover remaining at a safe standoff distance so that in-situ science may still be performed after the Earth-return sample departs.

Figure 9: Lander-based MAV Concept

CONCLUSIONS

Second generation lander/rovers offer significant improvements over first generation systems. Higher masses may be delivered to the surface, and the precision and safety of landing is substantially improved. Higher landing precision is combined with longer range and lifetime to enable a new class of "go-to" missions where a specifically identified target may be investigated. Long range, long life, and sophisticated in-situ and sampling instruments enable a higher level of science return than in previous missions.

The SLML has recently been advanced to project status at the NASA Jet Propulsion Laboratory, and scientific definition of the mission is underway. Further investigations of MSR mission architectures are underway by NASA internal and industry external teams. More capable rovers will play a strong role as NASA continues its exploration of the Red Planet.

REFERENCES

[1] D. Lavery. Program Architecture for the Robotic Exploration of Mars. SAE 2001-01-2137. In *Proceedings of the 31st International Conference on Environmental Systems*, Orlando, FL, July 2001.

[2] B. Goldstein and J. Matijevic. The Mars Exploration Rover: An In Situ Science Mission to Mars. SAE 2001-01-2136. In *Proceedings of the 31st International Conference on Environmental Systems*, Orlando, FL, July 2001.

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ADDITIONAL SOURCES

http://mars.jpl.nasa.gov

DEFINITIONS, ACRONYMS, ABBREVIATIONS

ASI: Agenzia Spaziale Italiana
CNES: Centre National d'Etudes Spatiales
EDL: Entry, Descent, and Landing
JPL: Jet Propulsion Laboratory
MAV: Mars Ascent Vehicle
MEP: Mars Exploration Program
MER: Mars Exploration Rover
MOC: Mars Orbital Camera
MSR: Mars Sample Return
NASA: National Aeronautics and Space Administration
OS: Orbital Sample
RPS: Radioisotope Power System
SLML: Smart Lander/Mobile Laboratory