PRELIMINARY EVALUATION OF ENGINEERING CONSTRAINTS OF MARS SAMPLE RETURN LANDING SITES.

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Introduction: This abstract reports on preliminary evaluation of engineering constraints on potential landing sites for the Mars Sample Return (MSR) missions. These constraints are derived from the preliminary engineering design for the landers, the preliminary Earth-Mars transfer trajectories, and the preliminary entry, descent and landing scenario. This work is being done to assist the project in evaluating the impact of the mission and lander designs to the types of terrains available for landing and their surface characteristics, derived from existing remote sensing data and models based on them. The approach follows directly from that used to select the Mars Pathfinder landing site and that used to evaluate and downselect sites for the Mars Surveyor 2001 lander [1, 2]. As for these activities, the Mars Sample Return landing site selection activity will be done in an open environment with multiple workshops designed to solicit and receive science community input and involvement. This abstract does not deal with the scientific aspects of landing site evaluation, which depends on the science objectives of the mission and the payload.

Preliminary Engineering Constraints: The engineering constraints are derived from the spacecraft design and landing scenario as defined by the MSR engineering team. Present targeting capabilities suggest a 20 km long landing ellipse. All elevations within the landing ellipse must be below 2.5 km with respect to the 6.1 mbar geoid to allow the parachute sufficient time to bring the spacecraft to terminal velocity before the retro-rockets fire. The actual requirement derives from the density profile of the atmosphere above the surface, which is translated into an elevation requirement via atmospheric models relative to the geoid, season, location, and time of entry. Preliminary work also suggests a weak minimum elevation constraint (-1 km with respect to the 6.1 mbar geoid) from the maximum surface pressure for opening the solar panels and the maximum amount of atmosphere that the Mars ascent vehicle can travel through. A preliminary conversion from the 6.1 mbar geoid to the improved Mars Global Surveyor (MGS) geoid derived from Mars Orbiter Laser Altimeter (MOLA) elevations and MGS gravity [3] suggests the MOLA derived geoid is about 1.6 km lower in pressure (5.2 mbar). To convert from the above elevations to MOLA elevations, subtract 1.6 km [3]. In addition, because the surface atmospheric pressure varies by 25% seasonally, these effects must be accounted for [see 3 for method]. Preliminary rough corrections suggest landing sites must be an additional 1 km lower for the 2003 launch opportunity landing and up to 1 km higher during the 2005 launch opportunity landing.

The MSR lander, like any solar powered spacecraft on the surface of Mars, requires as much power from the Sun as possible. Large 8-10 m^2 fans covered with solar cells deploy from either side of the lander to obtain the required solar power to operate the lander during the design lifetime of the prime mission (90 sols). To maximize the solar power, the lander must be near the subsolar latitude, which is ±25° from the equator. The specific latitude results from the selected Earth-Mars transfer trajectory, which effectively fixes the season (L_s) of arrival. For the launch opportunity in 2003 and the minimum energy transfer trajectory, the subsolar latitude at arrival is 16.5°S and moves to 2.4°N three months later (the design lifetime of the mission). As a result, the lander is being designed to accommodate landing within 10° of 5°S, or 5°N to 15°S. There is some flexibility to vary the arrival date (by modifying the transfer trajectory) from up 1.5 months earlier to 2 months later for this opportunity, which changes the subsolar latitude at landing by up to 20°. In any case, landing sites would be selected from a 20° latitude window centered around the latitude that optimizes mission lifetime (which is the 5°S latitude for the nominal design). For the launch opportunity in 2005 and the minimum energy transfer trajectory being considered, arrival is near the subsolar latitude of about 25°N and moves south with time. For this opportunity, landing sites will likely be constrained to be between 25°N and 5°N.

The preliminary design for the MSR lander also places constraints on the landing site. The lander design presently includes three legs that deploy during final descent that are connected by a series of stabilizer bars. Retro rockets bring the spacecraft to a soft landing on Mars. It's footprint is larger than other legged landers (3.5 m across) to accommodate the rover and the Mars Ascent Vehicle and the solar panels sweep out an even larger area after they deploy so that the lander is susceptible to large slope changes and high rocks on the surface. In addition, severe surface slopes could cause early or late firing of the retro-rockets during terminal descent. The three-legged lander is stable on surfaces with slopes up to 15°. Any tilt of the lander could adversely affect power generation on the surface. Steep slopes are also a concern for rover power generation and trafficability.

Rocks are also a major concern. During landing large rocks could severely damage the underside of the lander thermal enclosure, which is about 35 cm above the surface. In addition, each leg has two stabilizers that extend from the lander feet to the base of the lander that could be damaged by impact during landing. Rocks could also "catch" a lander foot during final landing resulting in lander tip over if the retro-rockets do not zero out all horizontal velocity. The preliminary engineering constraint is that the probability of landing on a rock >35 cm high should be less than about 1%. Extremely rocky areas also slow or impede rover trafficability. Active hazard avoidance is also being considered to avoid scarps and rocks during landing, which could allow targeting of potentially more hazardous areas.

Finally, extremely dusty environments can negatively impact the mission. The surface must be radar reflective for the lander to measure the closing velocity. Surfaces covered with extreme thicknesses of dust may not be reflective and may not provide a load bearing surface needed for safe landing and roving. Very dusty surfaces also could raise a plume of dust that could coat instruments and rocks. Dust also could be deposited on solar cells thereby reducing power and/or mission lifetime.

Landing Site Safety Criteria: To determine if the surface characteristics of a site meet the above engineering constraints, the evaluation, interpretation and modeling of remote sensing data are required [e.g., 1 and references therein, 2].

Higher resolution Viking Orbiter images allow more detailed evaluation of potential hazards at prospective locations than lower resolution images because smaller landforms can be identified. High resolution (1.5 m/pixel) Mars Orbiter Camera (MOC) images and roughly 6 m/pixel image swaths that cover part or all of a landing site will be required to better understand potential hazards at the meter scale.

Infrared thermal mapper (IRTM) and Thermal Emission Spectrometer data can be used to identify rocky areas and those dominated by dust [4]. Areas with very rocky surfaces (like the two Viking and Pathfinder landing sites) are also potentially hazardous. Model rock size-frequency distributions derived from those measured at the Viking and Earth analog sites [5] suggest that areas with total rock abundance [6] of <14% meet the preliminary engineering constraint of <1% chance of landing on a rock higher than 35 cm. Areas with <5% total rock abundance are likely to have surfaces dominated by dust [4] that may not be radar reflective or load bearing. As a result, areas with rock abundance between 5% and 14% likely meet the safety criteria. In addition, areas with fine component thermal inertias of $<4 \times 10^{-3}$ cgs units (10^{-3} cal cm^{-2} $s^{-0.5}$ K^{-1}) may be very dusty and may not provide a load bearing surface suitable for landing and roving [1]. Thermal Emission Spectrometer data will be used to update, refine and improve both the spatial and spectral data and to verify that the above criteria are met.

Radar data provides information on the elevation, roughness, distribution of slopes, and bulk density of the surface. A radar reflective surface is obviously required for safe landing. Areas with normal radar reflectivity greater than 0.05 will provide a reflective surface for the descent altimeter and will provide a load bearing surface with acceptable bulk density [e.g., 1]. One relation suggests that areas with radar derived root-mean-square slopes of <6° will have surface slopes exceeding 15° for about 5% of its surface [1]. Mars Orbiter Laser Altimeter (MOLA) data will be used to examine the slopes between measurements and relief at lander scale from the returned pulse spread [7]. The elevation will also be provided by MOLA and other radar data sets such as Continuous Wave, Arecibo, and Goldstone-Very Large Array will be used to show areas with anomalous properties, such as low reflectivity (e.g., stealth) or extreme roughness. Delay-Doppler radar data of analogous terrains will be examined as a general guide to the surface slope and reflectivity. Finally, albedo and Viking Orbiter color can be used to infer the coverage of dusty or weathered surfaces versus rocky or less weathered or dusty surfaces because dust has a high albedo and is bright in the red and less weathered surfaces have lower albedo and are less red [1].

Future Plans: We expect that these preliminary evaluations will be revised as the MSR missions are better defined. In this regard, the selection process includes two parallel activities in which engineers define and refine the capabilities of the spacecraft through design, testing and modeling and scientists define a set of landing site constraints based on the spacecraft design and landing scenario. These activities are continually revised as the lander design changes and as new information about Mars becomes available. We expect to hold a number of open landing site workshops to solicit input from the science community on potential landing sites and to assist in the analysis and interpretation of newly acquired MGS data.

References: [1] Golombek M. P. et al. (1997) *J. Geophys. Res. 102*, 3967-3988; Golombek M. P. et al. (1997) *Science 278*, 1743-1748; Golombek M. P. et al. (1999) *J. Geophys. Res. 104*, 8585-8594. [2] Golombek M. P. et al. (1999) Lunar and Planetary Science XXX, Abstract #1383; *Second Mars Surveyor Landing Site Workshop*, June 22-23, 1999, SUNY, Buffalo, NY, p. 37-38; *Workshop on Mars 2001: Integrated Science in Preparation for Sample Return and Human Exploration*, October 2-4, 1999, Lunar and Planetary Institute Cont. No. 991, Houston, TX, p. 38-40. [3] Smith D. E. and Zuber M. T. (1998) *Geophys. Res. Lett. 25*, 4397-4400. [4] Christensen P. R. and Moore H. J. (1992) in MARS, U. Ariz. Press, 686-727. [5] Golombek M. and Rapp D. (1997) *J. Geophys. Res. 102*, 4117-4129. [6] Christensen P. R. (1996) *Icarus 68*, 217-238. [7] Aharonson O. et al. (1998) *Geophys. Res. Lett. 25*, 4413-4416. Krevlavsky M. A. and Head J. W. (1999) *J. Geophys. Res. 104*, 21911-21924. Garvin J. B. et al. (1999) *Geophys. Res. Lett. 26*, 381-384.