PRELIMINARY ENGINEERING CONSTRAINTS AND POTENTIAL LANDING SITES FOR THE MARS EXPLORATION ROVERS.

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Introduction: This abstract describes the preliminary definition of engineering requirements on Mars Exploration Rover (MER) landing sites, maps these requirements into remote sensing criteria, and uses these criteria to identify potential landing sites. To first order, most of the engineering requirements are the same as for the Mars Pathfinder mission [1], because the landing system is the same.

Science objectives for the MERs relate to definition of the history of water and climate on Mars at locations where conditions may have been favorable for life. The goal of each MER is to determine the aqueous, climatic, and geologic history of a site on Mars where conditions may have been favorable to the preservation of evidence of possible pre-biotic or biotic processes. Scientific criteria used in identification and selection of landing sites include locations possessing clear evidence for surface processes involving ancient water. Hence, potential sites encompass a wide range of possible settings, including former lacustrine or hydrothermal environments.

Engineering Requirements: Analysis of the entry, descent and landing system and atmospheric profiles for the season and time of arrival indicates that the MER spacecraft are capable of landing below –1.3 km, with respect to the MOLA defined geoid [2]. This requirement stems mostly from the need for an adequate atmospheric density column for the parachute to bring the spacecraft to the correct terminal velocity. Because the landing system has no means to reduce horizontal velocity, low-altitude winds and wind shear together are major concerns and must be below roughly ~20 m/s.

Preliminary analyses of power generation/usage and thermal cycling of the rovers for the required 90 Sols restricts the landing sites to near the subsolar latitude at arrival. This translates to 5°N to 15°S for MER-A and 10°N to 10°S for MER-B, which arrives at Mars about 34 Sols after MER-A. Operations and Deep Space Network coverage considerations require the two landing sites to be separated by a minimum central angle of 37° on the surface.

Because of the arrival geometry and prograde entry into the atmosphere, landing ellipse size and orientation change significantly with latitude and time of arrival. Preliminary analysis of the expected flight path angle at atmospheric entry and dispersions produced by the atmosphere for the opening of the launch period yield 3 sigma landing ellipses for MER-A that vary linearly in length and azimuth from 77 km by 30 km, oriented at 66° at 15°S to 219 km by 30 km, oriented at 88° at 5°N. For MER-B, 3 sigma landing ellipses vary linearly in length and azimuth from 130 km by 30 km, oriented at 79° at 10°S to 338 km by 30 km, oriented at 99° at 10°N.

Surface slopes are an obvious concern for the landing system. Steep slopes can spoof the radar altimeter and cause premature or late firing of the solid rockets and airbag inflation. Small slopes over large distances can lead to significant additional horizontal velocity and prolonged bouncing by the lander within the inflated airbags. Reconstruction of Mars Pathfinder landing indicates the lander traversed a horizontal distance of about 1 km in more than 15 large bounces across the surface [3], even though it landed at 3 AM local time when winds should have been calm. Slopes can also affect the stability of the lander, rover deployment and trafficability, and power generation. As a result, surface slopes should generally be less than 15°. One relation between measured radar RMS slopes and slope suggests surfaces with <6° RMS slopes have about 5% of their surfaces with slopes >15° [e.g., 1].

The airbags of the Mars Pathfinder landing system were qualified to protect the lander from damage when landing on 0.5 m high rocks in any orientation [1]. This required a landing site with less than 1% of the surface covered by rocks greater than 0.5 m high. Model rock size-frequency distributions based on Viking, Mars Pathfinder and rocky locations on the Earth [4], generally suggest this requirement can be satisfied at locations with total rock coverage of <20% as derived from thermal infrared measurements [5].

The surface must be radar reflective for the descent radar altimeter to work properly, so radar reflectivity must be greater than ~0.05. The surface must be load bearing for the rover and excessive dust would coat rocks, which are of prime scientific interest (but which can impede mobility), and could reduce surface lifetime by covering the solar panels. Extremely high albedo and low thermal inertia regions should therefore be avoided [6]. Areas with fine component thermal inertia of less than 125-165 J m^{-2} $s^{-0.5}$ K^{-1} or SI units should therefore be avoided [7, 8].

Potential Landing Sites: MOLA elevations were plotted within the 25° latitude band from 10°N to 15°S. Because the southern hemisphere of Mars is dominantly heavily cratered highlands, little area is actually below –1.3 km in elevation for the MER-A (5°N to 15°S). The largest region below this elevation is in southern Elysium and Amazonis Planitiae. Unfortunately, most of this area (150°W to 200°W) is dominated by extremely low thermal inertia, with fine component thermal inertias below 125 and so is excluded. For the latitude band of MER-B (10°N to 10°S), more area is below –1.3 km elevation. Nevertheless, most of the area between 135°W and 190°W is excluded on thermal inertia grounds. Areas available to seek landing sites are thus reduced to southern Isidis and Elysium Planitiae in the eastern hemisphere and western Arabia Terra, Terra Meridiani, Xanthe Terra, Chryse Planitia, and the bottom of Valles Marineris in the western hemisphere.

Landing ellipses were placed in all locations that are below –1.3 km in elevation, have acceptable fine component thermal inertia values, and are free of obvious hazards in the MDIMs (Mars Digital Image Mosaics). This is exactly the same procedure employed to initially identify potential landing sites for Mars Pathfinder. Only sites that appear smooth and flat in the MDIM without scarps, large hills, depressions or large fresh craters (>5 km) were acceptable.

Nearly 200 potential landing sites meet these criteria: 100 sites for MER-A and 85 for MER-B. Even though the area available to land north of the equator is at least twice as great as south of the equator, the smaller ellipse size towards the south compensates. Geologic units accessible are diverse and range from Noachian Plateau dissected, hilly, cratered, and subdued cratered units to Hesperian ridged plains, channel materials, and the Vastitas Borealis Formation to Amazonian smooth plains, channel materials, volcanics, knobby materials, and the Medusae Fossae Formation. A complete listing of all of the sites can be viewed at http://webgis.wr.usgs.gov/mer and at http://marsoweb.nas.nasa.gov/landingsites/mer2003. For comparison, the landing ellipse for Mars Pathfinder (300 km by 100 km) and the 10° latitude band reduced available sites to just 10 [1].

Future Plans: Landing site selection activities include a first landing site workshop scheduled for January 2001. Abstracts were submitted and presentations on various aspects of landing site selection relevant for the MER missions have been scheduled. High-priority science sites in these abstracts and those identified by the community are being targeted by the Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC) during the initial period of the extended mission. Roughly 30 sites were identified, with remarkable consensus on one site, the Hematite site centered near 2°S, 2°W [9]. This site is the subject of about 10 talks in the workshop and was recommended by 14 participants. Next highest requested sites were crater lakes, with 5 recommendations for Gale, 3 for Gusev, 4 for other crater lakes, and 2 for a similar fluvial outflow region. Next highest were sites in Valles Marineris, with 4 recommendations for canyon sites, 4 for Valles Marineris outflow sites, and one for the Ganges sand sheet. Beyond these sites that received multiple recommendations are sites in Elysium, Isidis and the highlands. Note that if one lander were targeted to the Hematite site, the other lander could land no closer to the first than Valles Marineris due to the 37° operations exclusion zone.

Because the number of sites that meet the basic engineering constraints is so large, this process uses the science objectives of the mission as the main discriminator of sites to be investigated in detail. This contrasts markedly with previous site selection efforts for the Viking and Mars Pathfinder landers, in which the sites studied in detail were dominated by engineering considerations [1, 10].

Following this meeting a prioritized list of prospective landing sites will be targeted by MOC and other instruments. Following acquisition of new MOC images and landing site evaluations, the top sites for each rover will be selected sometime between June and October 2001. These sites would undergo further scrutiny and additional new MOC images would be acquired throughout 2001 and early 2002, when Mars Odyssey mission begins acquiring THEMIS (Thermal Emission Imaging System) data. Another open landing site workshop will be scheduled around April 2002 that focuses in detail on the highest priority sites. The project will select the highest 2 priority locations about 1 year before launch, when guidance algorithms are needed for the Delta launch vehicle engineers. These locations are boxes 10° in latitude by 15° in longitude. Landing sites within these boxes will continue to be evaluated until launch in June 2003, with final targeting of the specific landing ellipses at the first trajectory correction maneuver after launch.

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