CONSTRAINTS, APPROACH, AND STATUS OF MARS SURVEYOR '01 LANDING SITE SELECTION.

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Introduction: There are many similarities between the Mars Surveyor '01 (MS '01) landing site selection process and that of Mars Pathfinder. 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. As for Pathfinder, the safety of the site is without question the single most important factor, for the simple reason that failure to land safely yields no science and exposes the mission and program to considerable risk. The selection process must be thorough and defensible and capable of surviving multiple withering reviews similar to the Pathfinder decision. On Pathfinder, this was accomplished by attempting to understand the surface properties of sites using available remote sensing data sets and models based on them (see [1] for a description of the approach and [2] and [3] for the results). Science objectives are factored into the selection process only after the safety of the site is validated. Finally, as for Pathfinder, the selection process is being done in an open environment with multiple opportunities for community involvement including open workshops, with education and outreach opportunities.

Engineering Constraints: The engineering constraints are derived from the spacecraft design and landing scenario as defined by the MS '01 engineering team. Present targeting capabilities using aeromanuevering result in a 26 km diameter landing circle at the equator that varies linearly to about 20 km diameter at 2°S. 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. The surface pressure must also be less than 10.6 mbar to allow proper opening of the solar panels, which requires that elevations be above -3 km. The latitude of the landing site is presently limited by lifetime requirements of the mission (90 days), which translates into temperature and solar power considerations to be near equatorial and between 3°N and 12°S, which has been significantly narrowed from the original 15°N to 15°S.

Severe surface slopes negatively impact the lander and rover in a number of ways. During terminal descent a radar altimeter measures the closing velocity and triggers the firing of the retro-rockets for safe landing. For example, the rockets might begin firing on top of a mesa, only to be carried by residual horizontal velocity to the edge of the mesa with a precipitous drop off resulting in insufficient propellant to land safely. Alternatively, the rockets might fire too late if its horizontal velocity carried it towards a steep rise during landing. The three-legged lander is stable on surfaces with slopes up to 16°. Allowing for a 6° tilt due to maximum leg crush during lander impact, limits the acceptable surface slope to about 10°. Finally, 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. Depending upon the amount of leg crush that occurs during landing, the underside of the lander thermal enclosure could be as low as 33 cm above the surface, which limits the height of rocks that can be safely spanned. 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. The preliminary engineering constraint is that the probability of landing on a rock >33 cm high should be less than about 1%. Extremely rocky areas also slow or impede rover trafficability. The Sojourner rover on Pathfinder (a nearly identical rover will be flown on MS '01) traversed and maneuvered slowly and carefully in local areas with >20% rock coverage, but maneuvered easily and took long traverses without stopping in areas with <15% rock coverage.

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 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. Because 20 year old Viking data are used to evaluate the sites, the initial means of inferring the surface characteristics are very similar to those used by Pathfinder [e.g., 1 and references therein].

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. Landforms about 250-500 m across can be identified in Viking images of about 50-100 m/pixel, which are preferable to areas covered by lower resolution images. Slopes over tens of meters scale can be investigated in areas covered with high-quality and -resolution images using photoclinometry or photogrammetry. Potential landing sites should be covered by <100 m/pixel images and appear hazard free with relatively few large scarps, slopes, mesas, hills, and craters.

Infrared thermal mapper (IRTM) 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] (and that accurately predicted those at the Pathfinder site) were used to show that areas with total IRTM rock abundance [6] of <10% (roughly similar to the Viking Lander 1 site without the outcrops) meet the preliminary engineering constraint of <1% chance of landing on a rock higher than 33 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 10% likely meet the safety criteria. In addition, areas with fine component thermal inertias of $<4 \times 10^{-3}$ cgs units (or 10^{-3} calories $cm^{-2}\ s^{-0.5}\ K^{-1}$) may be very dusty and may not provide a load bearing surface suitable for landing and roving [1].

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 <4° will have surface slopes exceeding 10° for about 4% of its surface [1]. 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].

Areas that have: (1) elevation below 2.5 km and above -3 km in the USGS DTM (Digital Terrain Model); (2) locations between 3°N and 12°S; (3) rock abundance between 3% and 13% (which must be later verified to be within 5%-10%); (4) fine component thermal inertia above 4×10^{-3} cgs units; and (5) contiguous 50 m/pixel or better Viking Orbiter images are shown on our web site at http://mars.jpl.nasa.gov/2001/landingsite/index.html. Approximately 30 locations meet these remote sensing safety requirements. An additional 10 locations meet the requirements with lower resolution (<100 m/pixel) Viking Orbiter images. These locations are in Melas Chasma, Eos Chama and others at the eastern end of Vallis Marineris, Maja Valles, Terra Meridiani, and north of Hesperia Planum. Most locations are in Noachian heavily cratered terrain, although some are in Hesperian channel materials.

Future Data: A major difference between the MS '01 landing site selection process and that of Pathfinder is the availability of new information from the completed Pathfinder mission and the ongoing Mars Global Surveyor (MGS) mission. Although the timeline for site selection requires the activity to begin with existing Viking data, these data sets will be improved and augmented substantially with MGS data acquired in 1999 (note that data acquired by the Mars Climate Orbiter will be too late to affect the selection, which must be finalized by 1/00). High resolution (1.5 m/pixel) Mars Orbiter Camera (MOC) images and roughly 6 m/pixel image swaths are being acquired and will be required in any approved landing site or in nearby similar terrain to identify potential hazards at the meter scale. Thermal Emission Spectrometer data will be needed to update, refine and improve both the spatial and spectral data from the Viking IRTM and to assure that the rock abundance is between 5% and 10%. Mars Orbiter Laser Altimeter (MOLA) data (and gravity data) will be needed to improve the shape, geoid and elevation of prospective sites as well as to examine the slopes between measurements and relief at lander scale from the returned pulse spread. Agreements with all MGS investigators have been made to collect and make available relevant data in a timely manner.

A final difference between the MS '01 landing site selection process and that of Pathfinder is the reliance on delay-Doppler radar data, which Pathfinder required to constrain the elevation and roughness. For MS '01, the elevation will 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. MOLA data will also be used to assess slopes and local relief.

Data sets, announcements and a schedule for the selection of the MS '01 landing site will be maintained on our web site (URL above). A landing site workshop has been scheduled for late June after which the number of sites being studied in detail will be limited to order 10. Targeted MGS data will be evaluated and site selection will take place by 1/00. The presentation will include an update and status report on these activities.

References: [1] Golombek M. P. et al. (1997) *JGR 102,* 3967-3988. [2] Golombek M. P. et al. (1997) *Science 278,* 1743-1748. [3] Golombek M. P. et al. (1999) *JGR, 104,* 8585-8594. [4] Christensen P. R. and Moore H. J. (1992) in MARS, U. Ariz. Press, 686-727. [5] Golombek M., and Rapp D. (1997) *JGR 102,* 4117-4129. [6] Christensen P. R. (1996) *Icarus 68,* 217-238.