Navigation Strategy for the Mars 2001 Lander Mission

Robert A. Mase
David A. Spencer[†]
John C. Smith
Jet Propulsion Laboratory

Dr. Robert D. Braun
NASA Langley Research Center

Extended Abstract

The Mars Surveyor Program (MSP) is an ongoing series of missions designed to robotically study, map and search for signs of life on the planet Mars. The MSP 2001 project will advance the effort by sending an orbiter, a lander and a rover to the red planet in the 2001 opportunity. Each vehicle will carry a science payload that will investigate the Martian environment on both a global and on a local scale. Although this mission will not directly search for signs of life, or cache samples to be returned to Earth, it will demonstrate certain enabling technologies that will be utilized by the future Mars Sample Return missions.

One technology that is needed for the Sample Return mission is the capability to place a vehicle on the surface within several kilometers of the targeted landing site. The MSP'01 Lander will take the first major step towards this type of precision landing at Mars. Significant reduction of the landed footprint will be achieved through two technology advances. The first, and most dramatic, is hypersonic aeromaneuvering; the second is improved approach navigation. As a result, the guided entry will produce in a footprint that is only tens of kilometers, which is an order of magnitude improvement over the Pathfinder and Mars Polar Lander ballistic entries. This reduction will significantly enhance scientific return by enabling the potential selection of otherwise unreachable landing sites with unique geologic interest and public appeal. A landed footprint reduction from hundreds to tens of kilometers is also a milestone on the path towards human exploration of Mars, where the desire is to place multiple vehicles within several hundred meters of the planned landing site.

Hypersonic aeromaneuvering is an extension of the atmospheric flight goals of the previous landed missions, Pathfinder and Mars Polar Lander (MPL), that utilizes aerodynamic lift and an autonomous guidance algorithm while in the upper atmosphere. The onboard guidance algorithm will control the direction of the lift vector, via bank angle modulation, to keep the vehicle on the desired trajectory. While numerous autonomous guidance algorithms have been developed for use during hypersonic flight at Earth, this will be the first flight of an autonomously directed lifting entry vehicle at Mars. However, without sufficient control and knowledge of the atmospheric entry conditions, the guidance algorithm will not perform effectively. The goal of the interplanetary navigation strategy is to deliver the spacecraft to the desired entry condition with sufficient accuracy and knowledge to enable satisfactory guidance algorithm performance.

Specifically, the entry flight path angle must not exceed 0.27° to a 3σ confidence level. Entry errors will contribute directly to the size of the landed footprint and the most significant component is entry flight path angle. The size of the entry corridor is limited on the shallow side by integrated heating constraints, and on the steep side by deceleration (g-load) and terminal descent propellant. In order to meet this tight constraint it is necessary to place a targeting maneuver seven hours prior to the time of entry. At this time the trajectory knowledge will be quite accurate, and the effects of maneuver execution errors will be small. The drawback is that entry accuracy is dependent on the success of this final late maneuver. Because propulsive maneuvers are critical events, it is desirable to minimize their occurrence and provide the flight team with as much response time as possible in the event of a spacecraft fault. A mission critical maneuver at

[†] MSP2001 Mission Manager

Entry – 7 hours does not provide much fault tolerance, and it is desirable to provide a strategy that minimizes reliance on this maneuver.

This paper will focus on the improvements in interplanetary navigation that will decrease entry errors and will reduce the landed footprint, even in the absence of aeromaneuvering. The easiest to take advantage of are improvements in the knowledge of the Mars ephemeris and gravity field due to the MGS and MSP'98 missions. Improvements in data collection and reduction techniques such as "precision ranging" and near-simultaneous tracking will also be utilized. In addition to precise trajectory control, a robust strategy for communications and flight operations must also be demonstrated. The result is a navigation and communications strategy on approach that utilizes optimal maneuver placement to take advantage of trajectory knowledge, minimizes risk for the flight operations team, is responsive to spacecraft hardware limitations, and achieves the entry corridor.

The MSP2001 mission is managed at JPL under the auspices of the Mars Exploration Directorate. The spacecraft flight elements are built and managed by Lockheed-Martin Astronautics in Denver, Colorado.