MARS HOPPER FOR LONG-RANGE MOBILITY, REGIONAL SURFACE AND LOWER ATMOSPHERIC INVESTIGATIONS, AND IN-SITU RESOURCE UTILIZATION

Robert C. Moeller[1], Kristopher L. Kriechbaum[1], and Michael J. Sekerak[2], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive MS 149-100, Pasadena, CA 91109, robertcm@jpl.nasa.gov, [2]Univ. of Michigan, Plasmadynamics and Electric Propulsion Laboratory, 1919 Green Rd B107, Ann Arbor, MI., 48109.

Introduction: The Mars Hopper is a concept that could enable a versatile, long-range mobility platform for scientific instrumentation to study the surface and atmosphere of Mars in-situ. After initial entry, descent, and landing, the hopper would investigate the landing site and use in-situ resource utilization (ISRU) to produce propellant from the Martian atmosphere. This propellant would be used to propulsively "hop" up to approximately 70 km over the surface via ballistic suborbital rocket trajectories. After each hop, the site characterization and ISRU propellant production would repeat to prepare for the next hop. Profiles of atmospheric properties could be obtained during hops, and surface instruments could study the multiple sites after each landing. Over multiple hops, the system would explore a broad region of Mars (potentially 100s of km), with much greater spatial extent and accessibility in and around compelling regions than are possible with conventional mobility systems.

The mission concept presented here is based upon a Caltech student design study in which the authors participated in 2000 (itself built upon a 1987 concept study by Sercel et al.), as well as a follow-on short JPL Team X assessment study.[1][2][3] For the point design, the system would use an ISRU subsystem to separate Martian CO_2 into CO and O_2 for the rocket propellants and advanced radioisotope power sources (ARPS). However, a number of new trade space options could be considered, including other ISRU and propellant subsystem options, solar-powered architectures, and lower mass/shorter-duration (and lower cost) systems designed for much smaller range hops.

Addresses the Challenges: The Mars Hopper concept enables several unique and compelling mission and system aspects that directly address all three of the challenge areas in the LPI call:

1) Challenge Area 1: Instrumentation and Investigation Approaches – *The Mars Hopper could provide a multi-purposed, long-range mobility platform for abundant scientific return at both macro and micro scales in the atmosphere and on the surface of Mars.* The Mars Hopper could enable up to approximately 70km horizontal range per hop and ~45km vertical height per hop, enabling instruments to conduct in-situ investigations of multiple sites in a large region over the course of the mission. This approach would also provide unique aerial vantage points and atmospheric vertical sampling during the hops. In addition, if a CO-O_2 propulsion system were used (with CO_2 as exhaust), it would mitigate the challenge of local site contamination due to propellant exhaust inherent to most other landing propulsion systems.

2) Challenge Area 2: Safe and Accurate Landing Capabilities, Mars Ascent, and Innovative Exploration Approaches – *The Mars Hopper could enable an innovative approach to large-scale regional exploration of the surface and lower-to-mid atmosphere of Mars and demonstration of critical technologies.* Via multiple hops, 100s of km could be explored over the course of the mission. The hopper also provides an excellent platform for demonstration and validation of key technologies to support potential future Mars sample return and human missions. The hopper could validate the same navigation and control technologies required for landing and ascent from the surface of Mars, and ISRU for O_2 and propellant production. The hopper could potentially also be used as the first stage for a sample return Mars ascent vehicle (MAV).

3) Challenge Area 3: Mars Surface System Capabilities – In addition to the capabilities listed above, *the Mars Hopper could provide unique access to scientifically-compelling regions through the ability to hop over, into, and out of areas with challenging terrain inaccessible to conventional surface mobility systems.* Such locales might include canyons, hillsides, and other interesting features on Mars. The hopper could access these areas by navigating around rugged terrain and large slopes that might be inaccessible to rovers and other surface-bound mobility systems. The hopper also enables much farther mobility, and even greater range is possible if designed for longer ISRU time or higher power. Alternatively, a smaller system could be designed for shorter hops.

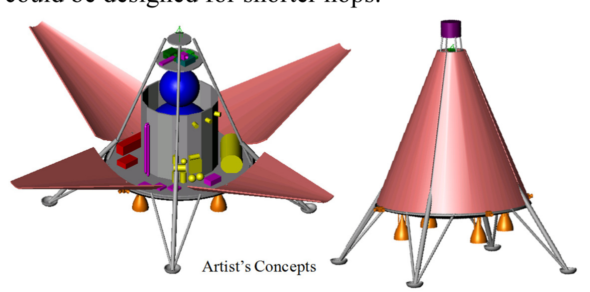

Fig. 1. Configuration of Mars Hopper spacecraft with radiator petals open for surface operations (left) and closed for hop (right).

Reference Point Design Features: A small study in 2000 resulted in a point design for the mission and system concept for which some key features are summarized below.[1] Fig. 1 shows a notional configuration for the hopper. However, note that a fresh examination of the design trade space should be undertaken, as prioritized by new science objectives, and could result in a smaller, lower-mass, and lower-cost system.

Mission and system overview: The notional design was a 5-year mission, with one ~70 km hop per 235 sols (5 or more hops expected). System estimates with contingency included 1610 kg dry mass (without initial entry consumables) and wet masses of 2310 kg at Earth launch or 2810 kg at Mars hop launch (filled).

Payload: The hopper would be designed as a flexible carrier of multiple candidate payload configurations. The 2000 study was primarily an engineering proof-of-concept study using a 50 kg payload allocation. Candidate instruments might include high-resolution and panoramic cameras, radar (also for navigation), deployment of a network of seismometers and magnetometers, a robotic arm and scraper, detectors (on the legs or arm) for near-subsurface water and soil properties, and atmospheric/meteorology package.

Mission Design: The flight system would launch direct to Mars on an Earth escape trajectory. Upon Mars arrival, the hopper would commence entry, descent, and landing (EDL) with a single-use entry heat shield (jettisoned later). Both supersonic and subsonic parachutes would also be deployed, similar to previous Mars missions. Delta-V of 250 m/s would be allocated for terminal descent, maneuvering for hazard avoidance, and soft landing. For the hops, a burnout velocity of ~530 m/s could be achieved, resulting in a ~70 km range. Before lift-off, the side panels would close. During descent, the hopper would turn its base (with reusable, thermal-protecting tiles) in the velocity direction to enable descent thrusting and higher drag.

Propulsion: A new bi-propellant propulsion subsystem would need to be developed and flight qualified. The reference design included a CO-O_2 system (but could be other technologies such as CH_4-O_2, depending upon choice of ISRU) with four main engines designed for an effective I_{sp} of ~232 s on the surface.

ISRU Propellant Production: The ISRU subsystem for the reference design was for collecting CO and O_2 from CO_2 abundantly available in the Martian atmosphere. Other approaches could also be explored further, such as methane and oxygen production by bringing hydrogen on-board but were not selected in the 2000 study. In the notional subsystem, sorption pumps acquire CO_2 from the atmosphere and a zirconia cell "cracks" the CO_2. A refrigerator system cools and condenses the O_2 and CO into separate tanks.

Power: The 2000 study assumed availability of multiple ARPS, which could provide 520 W continuous (day/night) electrical power for ISRU propellant production, plus modest additional power for other subsystems. Significant waste heat could also be provided by the ARPS, and this was assumed to be available to the ISRU system for heating the sorption pumps. However, an all solar-powered option could also be considered in a future trade study.

Thermal and Structures: The aerostructure would be conical with four "petal" sections that open and close to expose or protect the interior. Heat pipes transport waste heat from the ARPS to the ISRU subsystem during operation or shunt to the open radiator panels when off. High-temperature reusable surface insulation tiles would cover the base of the cone for thermal protection during each hop's descent.

Avionics and GN&C: The hopper would provide autonomous control during initial EDL and hops. Radar and imaging would be used for ranging and hazard avoidance. The hopper's flight computers would control the spacecraft during transit to Mars. The telecom subsystem would provide a UHF link with Mars orbiters and a direct-to-Earth X-band link.

Conclusions: The Mars Hopper would enable both macro and micro scale in-situ investigations of the atmosphere and surface of Mars. Up to 70km per hop and 100s of km over the whole mission allow wide regional exploration and access to unique regions inaccessible to conventional surface mobility systems. The Mars Hopper would also provide an excellent platform for demonstrating critical technologies (e.g., ISRU, landing hazard avoidance, ascent) to feed-forward to potential Mars sample return and human exploration. If a CO-O_2 propulsion system were used, the CO_2 exhaust mitigates landing site contamination. A future study should examine alternative trade space options, including other ISRU propellants, solar power, and lower-mass/shorter-duration/lower-cost systems as driven by new science and measurement priorities. A study could also examine using the hopper as the first stage of a Mars ascent vehicle for potential sample return.

References:

[1] Moeller R. C., Sekerak M. J., Kriechbaum K. L., Schell S., Tretten A., Higbie M., and Romberg F. (2000), Mars Hopper Mobile Platform Study Final Design Review Presentation Report.

[2] Oberto et al. (2000), Mars Hopper Team X report, Jet Propulsion Laboratory, Pasadena, CA.

[3] Sercel J. C., Blandino J. J., and Wood K. L. (1987), The ballistic Mars Hopper: An alternative Mars mobility concept. In: AIAA Joint Propulsion Conference, San Diego, CA.