The Mars Hopper: a radioisotope powered, impulse driven, long-range, long-lived mobile platform for exploration of Mars. Steven D. Howe[1], Robert C. O'Brien[1], Nathan Jerred[1], Spencer Cooley[1], John Crepeau[2], Steve Hansen[3], Andrew Klein[4]

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Introduction: Planetary exploration mission requirements are becoming more demanding. Due to the increasing cost, the missions that provide mobile platforms that can acquire data at multiple locations are becoming more attractive. Wheeled vehicles such as the Mars Exploration Rovers have proven extremely capable but have very limited range and cannot traverse rugged terrain. Flying vehicles such as balloons and airplanes have been proposed but are problematic due to the very thin atmospheric pressure and the strong, dusty winds present on Mars. The Center for Space Nuclear Research (CSNR) has designed an instrumented platform that can acquire detailed data at hundreds of locations during its lifetime - a Mars Hopper.

The Mars Exploration Rovers, Spirit and Opportunity, have performed remarkably for 5 years and have covered 4.8 and 10.7 miles, respectively. The Phoenix lander has sampled the Martian surface close to the northern polar cap of Mars but only at one location. Spot sampling at a few locations, especially locations that are safe landing sites, will not provide an accurate geophysical map of Mars. In addition, if humans are ever going to land on Mars, we must produce a much more detailed map of the resources, terrain and subsurface in order to know where to land.

More ambitious technologies must be developed and methods created to increase the science return for each launch, thus increasing the scientific value for the money spent for each mission. Several previous studies have proposed the use of "hoppers" powered by one means or another [1-5]. However, these concepts suffered from either short range (solar electric powered) or relatively short operational durations (chemical propellants carried from Earth). Conceivably, a long duration, robust Hopper can be placed on the surface of Mars that could acquire highly detailed data from the surface and subsurface, travel large distances to multiple sites and perform this task repeatedly. Such a platform enables an entire planetary surface to be accurately mapped and sampled with higher resolution than from orbiting platforms. In addition, if several such platforms could be simultaneously deployed from a single launch vehicle, a surface network of science stations would be possible that could provide long term assessment of meteorological conditions.

The CSNR is developing an instrumented platform that can acquire detailed data at hundreds of locations during its lifetime - a radioisotopic thermal rocket (RTR) Mars Hopper [6]. The platform will be able to "hop" from one location to the next every 5-7 days with a separation of 5-10 km per hop. Each platform will weigh around 52 kgs dry, i.e. empty of propellant, which is the condition at deployment. Consequently, several platforms may be deployed on a single launch from Earth. With a lifetime estimated at 5-7 years, the entire surface of Mars can be mapped in detail by a couple dozen platforms. Furthermore, the basic platform could be deployed to Europa or Titan with alterations-- the propulsion system and operations essentially will be the same.

The Mars Hopper concept utilizes energy from radioisotopic decay in a manner different from any existing radioisotopic power sources—as a thermal capacitor. Radioisotope sources have very high specific energy, J/kg, while having rather low specific power, W/kg. For example, Pu-238 has roughly 160,000 times the specific energy of high explosives (10 MJ/kg) but only produces around 0.4 kW/kg. By accumulating the heat from radioisotopic decay for long periods, though, the power output from the source can be dramatically increased for short periods. Thus, a radioisotopic thermal rocket (RTR) is possible.

The envisioned operational sequence is to utilize the 1 kWt decay heat from 2.5 kgs of PuO_2 to heat a block of beryllium to high temperatures. While the heating is taking place, some of the thermal power is converted to 250 W of electrical power to run a cryocooler. The cryocooler takes in the Martian atmosphere and liquefies it at roughly 2.8 MPa. The liquefied CO_2 is transferred to a tank which is held at 270 K. Once full, the power convertor is turned off and the core is allowed to increase in temperature. After the peak temperature of 1200 K is reached, a valve opens and gaseous CO_2 is pressure fed into the core. The gas is heated, expanded through a nozzle, and allowed to produce thrust. One half of the CO_2 propellant is "burned" for ascent. After a ballistic coast, the remaining propellant is used for a soft landing. Once landed, the process repeats. The results show that a platform carrying a 10 kg payload can hop repeatedly over the Martian surface until some part fails and the craft falters. From a power supply standpoint, the Hopper can operate for decades with the interval between hops growing with time. Initial results indicate that the Hopper could cover over 5-10 km each time.

The design of the Hopper is meant to be simple and robust in order to enable a long life and hundreds of landings. Currently, the CSNR is leading a team composed of CSNR staff, INL staff, and three universities to build a prototype Hopper to demonstrate the concept. The prototype will have an electrically heated core coupled to a tank of liquid CO_2. The liquefaction of Martian CO_2 is being demonstrated by the Utah State University. The power conversion subsystem to power the CO_2 liquefaction is being examined by the University of Idaho. Thermal isolation and heat transfer are being modeled by the Oregon State University and CSNR staff.

Preliminary results indicate that a small, compact system with relatively few parts can be designed that will utilize the in-situ Martian resources to "hop" around the surface. Such a probe will enable high-fidelity data to be acquired at hundreds of sites over a period of a few years. Potentially, this system can travel from the equator to a pole in two years. Thus, a comprehensive set of data using the same instruments can be acquired over much of the surface of Mars. In addition, depositing several of these platforms on Mars will allow the entire surface to be mapped within a decade using only a few launches from Earth. Finally, the proof of concept for this system can be performed using electrically heated cores with a modest investment.

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