GROUNDBREAKING MARS SAMPLE RETURN FOR SCIENCE AND HUMAN EXPLORATION. B. A. Cohen, NASA Marshall Space Flight Center, Huntsville AL 35812 (Barbara.A.Cohen@nasa.gov).

Introduction: Partnerships between science and human exploration have recent heritage for the Moon (Lunar Precursor Robotics Program, LPRP) and near-earth objects (Exploration Precursor Robotics Program, xPRP). Both programs spent appreciable time and effort determining measurements needed or desired before human missions to these destinations. These measurements may be crucial to human health or spacecraft design, or may be desired to better optimize systems designs such as spacesuits or operations. Both LPRP and xPRP recommended measurements from orbit, by landed missions and by sample return.

LPRP conducted the Lunar Reconnaissance Orbiter (LRO) and Lunar Crater Observation and Sensing Satellite (LCROSS) missions, providing high-resolution visible imagery, surface and subsurface temperatures, global topography, mapping of possible water ice deposits, and the biological effects of radiation [1]. LPRP also initiated a landed mission to provide dust and regolith properties, local lighting conditions, assessment of resources, and demonstration of precision landing [2]. This mission was canceled in 2006 due to funding shortfalls. For the Moon, adequate samples of rocks and regolith were returned by the Apollo and Luna programs to conduct needed investigations.

Many near-earth asteroids (NEAs) have been observed from the Earth and several have been more extensively characterized by close-flying missions and landings (NEAR, Hayabusa, Rosetta). The current Joint Robotic Precursor Activity program is considering activities such as partnering with the New Frontiers mission OSIRIS-Rex to visit a NEA and return a sample to the Earth. However, a strong consensus of the NEO User Team within xPRP was that a dedicated mission to the asteroid targeted by humans is required [3], ideally including regolith sample return for more extensive characterization and testing on the Earth.

The Case for Mars Sample Return: Returned samples provide a unique perspective on the planetary environment, based on our ability to manipulate the sample, the capability to analyze the sample at high precision and accuracy, and the ability to modify experiments as logic and technology dictates over time [4]. For example, while the results of the Viking life detection experiments are still regarded by some as ambiguous, the return of samples to terrestrial labs would have enabled a battery of tests that would have left no doubt in interpretation of results.

The Decadal Survey sample-return mission will make significant progress regarding questions related to Mars habitability and past potential for life. It requires extensive surface mobility and capability to examine samples *in situ* to ensure the right samples are returned. However, a simpler, "groundbreaking" Mars Sample Return (GMSR) mission has been advanced several times as delivering a significant fraction of important Mars science objectives at a reduced cost. Such a mission architecture would do double duty for science and exploration at a price point well within the Mars Next Decade budget.

Science. The scientific value of a simplified sample return includes characterizing the igneous products and interior evolution of Mars, characterizing surface depositional processes and post-depositional histories, tying absolute ages to relative crater histories, and determining how regolith forms and is modified [5-7]. It is to be emphasized that the science community would not be satisfied with this approach if it were the only sample return mission under consideration for a Mars program; but if it is approached as the first in a series, it would enable paradigm-altering science and satisfy many stated science goals for MSR.

Engineering. Mechanical design and testing relies on knowledge and simulation of the surface environment. Lunar simulant has been extensively used for mobility tests, resource production, human health, and dust control technologies. Particle shape and size, composition, and bulk density may be characterized *in situ*, but more detailed measurements including trace composition, mineralogy relative to size and shape distribution, internal textures and compositions, particle strength, and abrasivity require sample return to create a better testing environment than the current Mars soil simulant JSC Mars-1 [8].

Human health. Recommended measurements needed for human health assessment include the presence of hexavalent chromium, pH and buffer capacity, and abundance of organic carbon [8], which may be done with well-planned in situ investigations. However, parallels with the work done by Lunar Airborne Dust Toxicity Advisory Group [9], which includes not just toxicology but also inhalation, dermal and ocular exposure, suggest that a sample of at least 50 g from the surface is greatly desired (J. James, pers. comm).

Programmatic risk. Currently, planetary protection guidelines dictate that returned Mars samples be kept in a CDC-type containment facility until acceptably tested and sterilized to minimize the threat to life on Earth. On the other hand, the Human Exploration program is considering immersing its crew in the Mars environment for up to 500 days after a slate of *in situ* microbial and toxicity measurements are made. Sample return provides the material to design new tests that cannot yet be imagined but may well become crucial in preventing crew loss at the surface of Mars.

GMSR Mission Architecture: The concept of Groundbreaking Mars Sample Return was developed by MEPAG [10, 11] to lower sample return mission cost and complexity. The GMSR architecture does without precision landing, extensive roving, and *in situ* instrumentation. It consists of a lander, extendable arm, simple sampling devices (scoop, sieve), and a context camera. The mission visits a site previously characterized by other missions to provide context and design envelopes. The collected samples include 500g of soil, dust, rock fragments, and atmosphere.

A direct entry/direct return architecture for MSR has been studied numerous times. A large launch vehicle delivers a payload to the surface of Mars consisting of sample collection and processing capabilities, a sample return capsule, and a Mars Ascent Vehicle (MAV) fueled for an ascent from Mars and flight back to Earth. Upon approach to Earth, the capsule separates from the rest of the vehicle and performs a high-speed re-entry similar to Stardust or Genesis.

Previous studies [12-15] estimate the landed mass of a direct-return mission as 1000-1500 kg (higher estimates include a rover), but find the direct return approach to be prohibitively expensive, because it requires a very large (=costly) large launch vehicle and lander to carry a fully fueled ascent vehicle. However, several advancements in technology encourage a re-examination of the direct return GMSR architecture. We highlight here two relevant developments from MSFC, though others certainly exist.

Launch Vehicle: The Space Launch System (SLS) provides around 50,000 kg to TMI (or 30,000 kg for the initial 70 mT configuation) direct from Earth. In an MSR study enabled by the Constellation-era heavy lift vehicle [16], aerocapture of 40 metric tons (mT) and landing of 8 mT were achieved. In this study, three 500 gm separate samples were returned from two separate Martian locations with a lander and rover having a mobility of >1 km, subsurface sampling, and additional investigations. This capability far exceeds the GMSR mission needs, opening the possibility of a GMSR mission sharing SLS launch capability and perhaps travelling to Mars after being launched to Earth-Moon L2 in an SLS reference mission.

DACS Thrusters: The Robotic Lunar Lander Development Program has invested in high thrust-to-weight thrusters for planetary landers, specifically missile-heritage, miniaturized thruster technologies used for Divert and Attitude Control Systems (DACS). MSFC hot-fire tested 100-lbf and 5-lbf thrusters with MMH/MON-25 under various pulsing durations, power levels, and propellant mixture ratios (Fig. 1). These tests show that DACS thrusters exhibit combustion stability, engine efficiency, and ability to perform pulsed and steady state burns at full power. Such thrusters need to be tested under Mars conditions but hold promise for lowering the mass of the MAV in a GMSR direct return architecture.

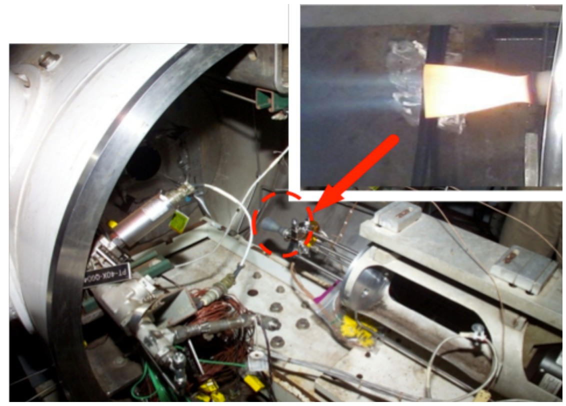

Figure 1: 100-lbf DACS thruster test.

Conclusions: A simplified approach to the first Mars sample return can return samples of paradigm-changing geologic importance and provide detailed knowledge to aid in planning safe and productive human exploration missions. The elements of such a mission (heavy lift, large landers, and high-speed re-entry) can also be used to provide test data for human systems design. Technological advances such as heavy-lift capability in the SLS, trajectories from Earth-Moon L2, and high thrust-to-weight ratio engines may enable a viable single-launch, direct return mission. A Groundbreaking MSR mission has not been updated or costed for a decade, so we suggest that the Mars Program commission an independent engineering and cost estimate for such a mission.

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