High-Performance Mars Ascent Propulsion Technologies with Adaptability to ISRU and Human Exploration. Mark A. Trinidad[1], Jacky G. Calvignac[1], Amy S. Lo[1], [1]Northrop Grumman Aerospace Systems, Redondo Beach, CA, 90278. mark.trinidad@ngc.com

Introduction: Budget cuts to the NASA Planetary Science Division, and in particular to the Mars Exploration Program, have prompted NASA to reformulate Mars Sample Return missions, consider new architectures, and explore use of game-changing propulsion technologies and the transition of robotic to human exploration Mars technologies. This abstract outlines a novel high performance propulsion system that provides maximized mission flexibility and provides a propulsion technology path to in-situ resource utilization (ISRU) as well as ascent vehicles for human exploration.

We propose a modularized liquid propulsion system/stage that can accommodate Mars storable high-performance liquid or gel propellants, and can be adapted to accommodate oxygen, hydrogen, and methane propellants for ISRU. The "thrust on demand" liquid propulsion architecture, configured with our multi-firing throttleable engines, has the unique capability to accommodate a broad range launch sites, launch angles, trajectories, payload mass and insertion orbits. Our Mars Ascent Propulsion System (MAPS) provides a modularized approach for future robotic or manned ascent vehicles where an optimized number of multiple MAPS systems – quantity determined by propulsion payload - can be attached to the outer structure of the ascent architecture for primary and reaction control propulsion to provide optimum delta-V.

Mars Ascent Propulsion System: One of the key features of MAPS is a coaxial tank design that efficiently packages oxidizer and fuel propellants while also serving as a primary load bearing structure. This allows the MAPS to be integrated as a vehicle structure such as the Mars Ascent Vehicle (MAV) concept illustrated in Figure 1, serve as multiple embedded propulsion cartridges to a larger ascent aero structure, and be stored/fueled in a depot of propulsion systems on the Mars surface.

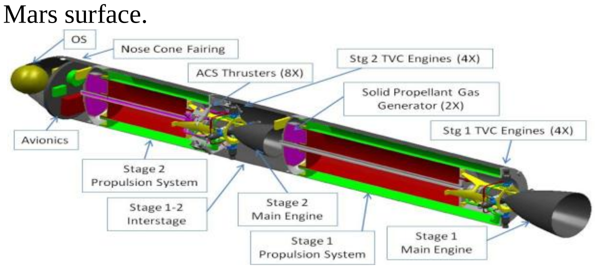

Figure 1. Baseline Mars Ascent Vehicle Design from NGAS 2010 Studies

Our Main and RCS liquid/gel engine designs are derived from our throttleable pintle engine heritage. Our main engine design, illustrated in Figure 2, is predicted to deliver over 330 seconds of specific impulse while operating at -40C. The engine design incorporates many features to minimize weight and maximize performance such as high-performance pintle injectors flight-proven on NGAS spacecraft. To reduce the weight associated with conventional solenoid valves, both the oxidizer and fuel valves are integrated into the head-end of the injector and are simultaneously actuated by a single pilot valve. Further mass reductions are achieved by utilizing NGAS' high thrust-to-weight ablative chamber technology with launch vehicle upper stage (TR-201), lunar descent (Lunar Excursion Module Descent Engine), and FMTI tactical pedigree.

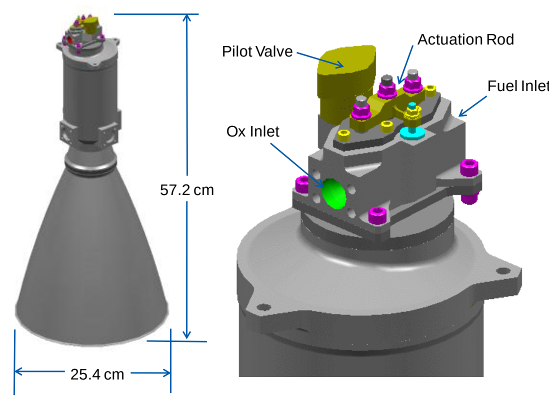

Figure 2. MAPS Main Engine (5.3 kN)

Adaptability to ISRU: Our MAPS technology is readily adaptable to ISRU propellants such as oxygen, hydrogen, and methane. Component modifications would focus on tank seal designs and incorporating our regeneratively-cooled engine capable of tolerating a broad range of propellant densities in gas or liquid states.

Our high-performance TR408 engine, illustrated in Figure 3, incorporates a regenerative cooled chamber coupled to a gas-gas triplet injector designed to inject gaseous propellants into the combustion chamber regardless of the propellant inlet conditions. Full vaporization of the cryogenic liquid propellants is ensured by the TR408 heat exchanger (HEX) chamber that both vaporizes the liquid propellants while also serves to cool the combustion chamber.

The TR408 has successfully demonstrated its ability to operate with cryogenic propellants near their freeze point, saturation point, and in a gaseous phase at the engine interface. Engine performance predictions indicate vacuum specific impulse of 348 seconds with a nozzle expansion ratio of 150:1.

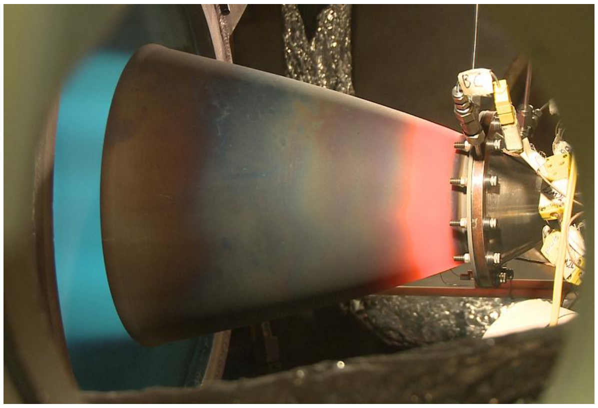

Figure 3. Regeneratively-Cooled TR408 LOX/LCH4 Engine

Long-Term Mars Storage: Our propulsion team has conducted over a decade of research and development to address the thermal and power challenges associated with long-term storage of propulsion systems in the Mars environment. Our MAPS tank design is uniquely equipped to serve both as a tank pressure vessel during operation and a large scale, fully compliant accumulator during storage. The tank compliance is enabled by independent pistons in both the fuel and oxidizer tank cavities. This feature accommodates significant propellant density changes that result from the varying Mars climates or ambient temperatures during long-term storage. While alternate systems may address the environment with significant power demands for thermal management, our long-term storage approach minimizes power demands and allows the system to quiesce to the Mars climate.

Selection of our candidate propellants maintained a focus on long-term storage requirements. For example, our high performance liquids have an operational temperature of -40C. Similarly, our candidate gels are formulated to accommodate storage temperatures to -80C and operation at -40C.

High Performance: The crux of this technology is its inherent ability to provide high performance. Our high performance metrics include: propulsion system mass fractions (wet mass to total mass); specific impulse; trajectory and delta-V optimization via restart and steering capability as well as minimized drag losses while escaping the Mars atmosphere. In addition, we have designed our system to deliver superior thermal performance by means of accommodating the Mars climate and minimizing the power demands during long-term quiescent storage.

Conclusion: Our modularized propulsion system and related technologies enable maximum mission performance and mission planning flexibility while maintaining a transition path to human exploration. The cross-cutting technologies provide an opportunity to infuse decades of propulsion technology research and development investments into a game-changing, modular propulsion system for Mars Ascent Propulsion as well as other science missions of interest such as Mars and Lunar probes.

References: [1] Trinidad, M.A, Zabrensky, E (NGAS), Sengupta, A. (JPL), "Mars Ascent Vehicle System Studies and Baseline Conceptual Design," IEEE Aerospace Conference, March 2012. [2] Zabrensky, E, Trinidad, M.A., TRW, "State of the Art Gel Propulsion System for the Mars Ascent Vehicle," Nov. 2002, JANNAF Propulsion Conference, Orlando FL. [3] Trinidad, M. A., Crofoot, T.A., Northrop Grumman Corp, "Development of Advanced Gel Propellants for In-Space Applications," 53rd JANNAF Propulsion Meeting, December 2005. [4] Trinidad, M.A., Hodge, K.F., Crofoot, T.A.,TRW, "Low Temperature Gel Engine Development for Controllable Thrust Propulsion," Nov 2002, JANNAF Propulsion Conference.