Throttle Control of an Extinguishable Solid Propellant Thruster System - Mars Lander. R.J.McCauley[1], W.G.Fletcher[2], and D.J.Crane[3], [1]NASA-MSFC Huntsville, AL 35812 (Rachel.J.McCauley@nasa.gov), [2]NASA-MSFC Huntsville, AL 35812 (George.Fletcher@nasa.gov), [3]NASA-MSFC Huntsville, AL 35812 (Deborah.J.Crane@nasa.gov)

Introduction: This proposal presents an opportunity for NASA to develop and demonstrate an innovative throttlable solid rocket motor through the combination of two developing technologies for use as thrusters for Mars surface landing vehicles. This concept is capable of improving accuracy for the navigation and control for entry and landing systems to support Mars exploration. Electrically-controlled extinguishable solid propellant (ESP) can be utilized in an on-command thrust controllable motor when designed with a mechanism that can control the nozzle throat area. The mechanism is typically a tapered plug, called a pintle. The pintle can be translated in and out of the throat causing the annular throat area to decrease or increase thrust capability.

Controllable solid rocket motors combine the simplicity of solid rockets and the thrust variation ability of the liquid and hybrid engines. Variable solid rocket thrust propulsion technology has been explored by government and industry since the end of the 20th century to find a solution to the propulsion requirements for the next generation of missiles and launch vehicles.

Controllable solid propulsion systems have had successful flight testing as part of the Orion Launch Abort System and vacuum atmospheric testing in the Lunar Softlandar program [1]. The current systems can evolve and when coupled with extinguishable solid propellant will enhance the thrust, operational extension, transport, and storage capabilities necessary for a Mars mission.

Design Configuration: A Mars lander thruster assembly of 3-4 valves may be configured in a cluster to control the lander descent direction and velocity and to provide vehicle stability. A valve controller is needed to allow for trajectory and velocity feedback information into the controller logic and to provide actuation of the pintle that controls the throat area for thrust demands. A cluster configuration can be designed to utilize replaceable propellant cartridges for repeatable thruster operations.

ESP Propellant: ESPs are safe and volumetrically-efficient solid motors that can be throttled, extinguished, and re-ignited like liquid propulsion systems. ESPs are inert unless ignited with an electric potential of sufficient magnitude. Once electrically ignited, burning rates can be increased by up to 20x (throttled) using electrical power and then switched off (extinguished) by removing the electrical power. Once extinguished, they can be re-ignited by applying electrical power. ESP formulations are based on high molecular weight (poly)vinyl alcohol, which swells and intermingles to create a tough plastisol solid when added to the ionic liquid oxidizer, hydroxylammonium nitrate stabilized with 5% ammonium nitrate (S-HAN-5). The S-HAN-5 is conductive and exhibits pyroelectric behavior (generating heat when subjected to an electric current) in the propellant. This property contributes to the safety of the plastisol, which cannot be ignited by spark or flame (in marked contrast to most solid propellants). ESP formulations are well-suited for long-term space applications and can be transported safely on the long duration trip to the Mars surface from Earth. They contain no volatile compounds and are manufactured using a water-based, solventless process, which allows them to be stored and operated in vacuum. ESPs are stable and safe to handle, and are classified by the Department of Transportation as Hazard Division 1.4 materials (minor fire or projection hazard). They can be classified as “green” propellants and are relatively non-toxic. ESP formulations produce only carbon dioxide, nitrogen, and water as major combustion products. [2-6] As a result of these properties, ESPs are well-suited for use in a cartridge-loaded propellant system, in which propellant is cast into multiple cartridges and the cartridges are loaded into the motor as needed. This allows thrusters to be re-used multiple times simply by replacing spent propellant cartridges.

Valves: The valves must be designed to withstand and control the hot gas environments. Current technology uses new materials such as a 4D C/C-SiC composite, refractory metals, metal alloys, and refractory metal coated composite parts to maintain structural integrity and to not ablate during operation, which would change the effective throat area. Therefore, a material can be selected that will not deteriorate the performance of the system following multiple on-demand uses.

Valve Actuators: The valve actuators must be designed to provide action time, vector thrust response, commanded thrust frequency response time, and mechanism torque/force capability necessary to meet the Mars lander mission needs.

Valve Controller: A control system must ensure pressure control, acceptable slew rate, pintle position control, sufficient memory and throughput margin, continued performance after overvoltage surge as well as other needs to ensure continual successful commanding of the valve system for thruster operation.

Power Source: A challenge for the design of this system will be the power source necessary to provide voltage to ignite the propellant. A replenishable power source will be needed for the expected repetition of thruster function. The team has considered using solar energy to recharge the power supply from the Mars as needed. Other means may require consideration that will provide the sufficient voltage required to ignite the propellant when commanded either remotely or directly.

Advantages: Controllable solid propulsion systems have several advantages over liquid propulsion systems for lander systems. Liquid propulsion systems use multiple fuel tanks, a combustion chamber, several valves, and a control system to manage valve functions. In comparison a typical solid propulsion system has only one igniter and nozzle, and a configured solid propellant grain in the combustion chamber. Solid rockets inherently have fewer working parts, which typically relates to lower risks and costs. Storage life of solid propulsion systems is also greater than that of liquid systems, in that they do not require regular maintenance. The disadvantage of standard solid propulsion has been the inability to be "throttled", thus the initiative to enhance controllable solid rocket propulsion technologies. Another advantage of variable thrust is the ability it provides for altitude compensation for the exit cone and optimum expansion at all boost and sustain thrust modes.

With utilization of the NASA in-house technical capabilities for the development of this controllable solid propellant thruster cluster assembly, development time and cost reduction may be realized through the ability to design, analyze, test and implement design modifications and retests with relative ease.

In-House Capability*:* NASA has the in-house capabilities to design, analyze, test and develop and integrate the propellant canisters, controller, power source and valve system. The extinguishable propellant development would be coordinated with Digital Solid State Propulsion LLC who has demonstrated the ignition and extinguishing response of the propellant. The challenge that exists is scalability necessary to provide the needed thrust for a Mars lander vehicle. The ability to ignite and extinguish an ESP has been demonstrated using thrusters with a diameter of 0.125 inches. Larger motors have been made and tested, but testing has been limited to throttling (rather than extinguishment and re-ignition). Currently, a MSFC Center Innovation Fund project is investigating the threshold at which throttling can still be achieved. Those results are expected by October 2012.

Summary: The development of the aforementioned technologies, when combined, has the potential to provide an innovative thruster cluster assembly for Mars exploration vehicles with descent maneuverability for Mars surface landing. By developing a design that can utilize a "green" solid propellant that is capable of being ignited and extinguished upon demand greatly expands the applications of a solid propellant. Use of this propellant also greatly improves safety considerations during long-term transport as opposed to highly volatile liquid propellants.

References:

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