LIGHTWEIGHT, HIGH PERFORMANCE, LOW COST PROPULSION SYSTEMS FOR MARS EXPLORATION MISSIONS TO MAXIMIZE SCIENCE PAYLOAD. H. P. Trinh, NASA Marshall Space Flight Center, Huntsville Alabama, huu.p.trinh@nasa.gov.

Introduction: Lightweight, high performance and low cost propulsion for Mars exploration missions will be based on utilization of new cold hypergolic propellants and leverage Missile Defense Agency (MDA) propulsion technology. Such a propulsion system will have significant payoffs and benefits for the NASA missions. The propulsion system will provide spacecraft *the capability to increase its payload significantly*. Compared to conventional propulsion systems, the reduction in the dry-mass of the proposed system could be as high as 30%. The reduction in the propulsion mass will allow the spacecraft to carry more payloads. The propulsion system will be capable of operating with a wide range of propellant temperature (-40 to 50 ^{o}C). Mars Sample Return missions and extended human-rated missions will benefit from this technology the most, due to the length of time that the spacecraft propulsion system must remain 'alive' while sitting on the surface of Mars.

Background: Propulsion systems with storable hypergolic propellants nitrogen tetroxide (NTO) and monomethylhydrazine (MMH) have selected for a trade study for Mars exploration missions. Hypergolic propulsion systems have been widely used on deep space missions due to their propellant storability, high performance, extreme reliability, robustness, and simplicity of ignition and combustion. The same hypergolic propellants would be used to provide high variable thrust for main spacecraft operations (such as orbit insertion, planetary surface descent and ascent, etc.), and pulsed attitude and reaction control operations, by means of pulsing or throttling.

NTO must be kept at nominal room temperature due to its relatively high freezing point (-11^{o}C); subsequently, its companion fuel (MMH) is usually maintained at the same temperature, although MMH has much a low freezing point (-52^{o}C) in order to manage and optimize engine and system efficiencies. For long duration flight missions, such as the Mars Sample Return, the relatively high freezing point of an NTO/MMH propulsion system will drive the system complexity and higher mass of the Mars Ascent Stage due to requiring significant and long-term heater power to the propellant systems. Over the last couple of decades, the propulsion community has studied a NTO mixture composed of 75% NTO and 25% Nitric Oxide (NO) by mass, often referred to as Mixtures of Nitrogen (MON)-25, instead of the basic NTO blends of MON-1 and MON-3 (with 1% NO and 3% NO, respectively) which have been commonly used by Air Force, NASA, and the commercial spacecraft industry. The oxidizer MON-25 has a freezing-point temperature of -55^{o}C similar to the one of MMH. Such propulsion systems are capable of operating at low temperature conditions**,** which promise to reduce, if not totally eliminate, the need for propulsion system heaters in a long-term Martian Surface environment.

Current and Future Work: With a similar interest in reducing propulsion system mass and power demand, the Missile Defense Agency (MDA) has matured miniaturized, high thrust-to-weight thrusters for use with higher MON oxidizers, such as MON-10, -15 and -25, for missile defense applications. For the last five years, NASA Marshall Space Flight Center has leveraged propulsion technology and architecture developed for MDA kinetic-kill vehicles. MSFC, partnering with Pratt & Whitney Rocketdyne (PWR) and NASA White Sands Test Facility (WSTF), has evaluated two miniaturized lightweight thrusters, heritage MDA hardware, for Robotic Lunar Lander (RLL) mission. The 100-lbf class thruster for Divert and Attitude Control Systems (DACS) and the 5-lbf class thruster for Attitude Control System (ACS), shown in figure 1, were successfully tested at WSTF in simulated space vacuum environments.

With the support from NASA Science Mission Directorate (SMD), MSFC, and PWR are refining the design of these high thrust-to-weight thrusters to better meet NASA's exploration needs. These design refinements will improve thruster performance and the capability to operate in long-duration, high-pulse burns and short-duration, low-impulse burns. The thrusters will operate with a lower inlet pressure, allowing the use of lower weight propellant tanks. The design improvement will also include redundant features, valve and injector redesign, high temperature materials, and thermal-vacuum life capability for planned NASA operations.

Benefits: Leveraging this flight-proven thruster technology not only provides less risk to the program, but also increases cost effectiveness and shortens the development time. Regarding benefits from this effort, advancing the thruster technology for NASA applications will offer the primary advantages as follows:

- *Lightweight and efficient system volume/ packaging*: The design leverages MDA miniaturized thrusters which feature integral valves and injector. Lightweight high-temperature composite thrust chamber/nozzle materials will significantly reduce propulsion system mass and volume.
- *Low cost:* Leverage MDA thrusters in mass production, with advanced and efficient manufactur-

ing techniques featuring low cost materials, demonstrate significant cost reduction potential for NASA applications.

- *Low temperature operation*: A propulsion system that utilizes MON-25/MMH propellants has a freezing point of -52^{o}C, which is significantly lower than the freezing point of conventional MON-3/MMH propulsion systems, thereby reducing or totally eliminating the need for an active thermal management system.

Cross-Cutting Technology: The technology is cross-cutting because it is applicable to Low Earth Orbit and Geosynchronous Earth Orbit (LEO/GEO) spacecraft, Lunar and Mars landers, and planetary orbiters. Geophysical lunar network mission studies indicate that such a propulsion system is an enabling technology for small spacecraft which often have extreme constraints in mass and system packaging.

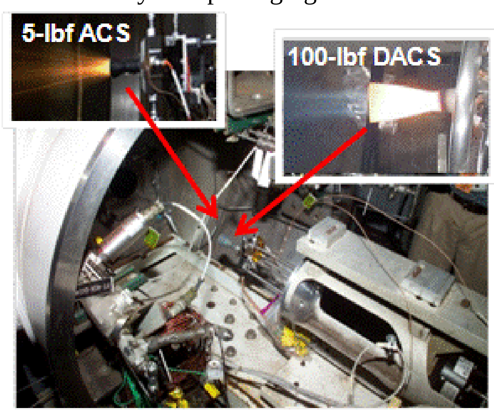

Figure 1: Successful Hot-Fire Evaluation of Heritage MDA Thrusters at WSTF in Vacuum Chamber