NOFBX™ MARS ASCENT VEHICLE: A SINGLE STAGE TO ORBIT APPROACH J. M. Vozoff[1], D. J. Fisher[2], and G. S. Mungas[3], [1]mv2space, [2]Firestar Technologies, [3] Firestar Technologies, 1122 Flight Line Street #76, Mojave, CA 93501, greg.mungas@firestar-tech.com.

Introduction: Nitrous Oxide Fuel Blend (NOFBX™) is a nitrous-oxide-based mono-propulsion technology developed specifically for a Mars Ascent Vehicle (MAV) application by Firestar Technologies. This development was funded primarily by the NASA Mars Program Office, NASA Small Business Innovation Research (SBIR), and NASA International Space Station (ISS). NOFBX™ propulsion system specific impulse performance equals or exceeds state-of-the-art nitrogen textroxide/ monomethyl hydrazine (NTO/MMH) systems, with the added advantages of restartability via spark ignition, deep throttleability (100:1), and high thrust-to-weight ratio. For a Mars MAV application, NOFBX™ mono-propellant and engine technology provides a Single State to Orbit (SSTO) ascent vehicle design option with significant benefits over solid and storable liquid propulsion approaches, including: 1) the reduced complexity and risk of a liquid monopropellant system compared to bi-prop systems, 2) the reduced complexity and risk of a single stage design over 2-stage systems by eliminating the upper stage, the associated interfaces, and stage-related critical events, and 3) lower pre-flight test cost and risk with the elimination of multiple configurations. NOFBX™ technology also provides operational benefits, as the propellant is non-toxic, non-contaminating to the planetary environment and storable over a very wide range of temperatures (<-70ºC to >+70ºC). Together these attributes offer the potential for dramatic simplification to the MSR program architecture as well as to the MAV itself, increasing margins, eliminating failure modes, improving reliability and decreasing cost.

NOFBX™ Technology: NOFBX™ is a completely non-toxic nitrous-oxide--based monopropulsion technology (14 patents published or pending in both U.S. and foreign jurisdictions) offering high performance (Isp up to ~325 seconds), storability over a wide temperature range, and lower cost compared to systems using hydrazine and its derivatives. NOFBX™ propellants were invented by Firestar Technologies (majority owner of ISPS) between 2003 and 2005 under funding from NASA's Mars Technology Program [1]. Since that time, Firestar has developed and tested five different NOFBX™ thruster designs, ranging from 0.45 N (0.1 lbf) to 445 N (100 lbf) thrust. The 445 N (100 lbf) version, with associated carbon-carbon nozzle, solenoid valve, throttle valve, flashback arrestor, injector head and igniter system, is currently approaching TRL 6, having successfully begun testing in a vacuum test facility.

NOFBX™ technology is more than the propellants themselves: it is also the essential surrounding technologies that enable this propellant to be safely and effectively employed to generate thrust in spacecraft and rocket propulsion applications. Some examples are flashback arrestor technologies, porous media injectorhead technology, microfluidic regererative thrust chamber technology and the associated thin-film fabrication technique, Firestar's developments to-date have demonstrated practical application of the technology [2].

Some advantages of NOFBX™ technology are listed in the table below.

Characteristic	NOFBX™ Advantage
Monopropellant	Less complex, reliable, low mass & cost
Self-pressurizing	No pressurant source required
High Isp	Vacuum Isp up to 325 s
High density Isp	Higher density than hypergolics – no thermal control demands
Spark-ignited	Unlimited restarts
Storable	Storage temperature: -70ºC to >+60ºC
Deep throttle	100:1, can be throttled down to ~1%
Cool-running	Outer thruster surfaces operate at <150ºC
Thrust/Weight	100:1 thrust:weight for Al thrusters
Propellant level monitoring	Remaining prop can be measured to within 0.1% for the final 15% of load
Compatibility	Compatible with most conventional feed system hardware components
Non-toxic constituents	Safe and lower cost ground handling and transportation – can be mixed on-site
Non-toxic effluents	N_2, CO, H_2O, H_2, CO_2. Water is only condensable.
Lower cost	Lower cost to manufacture and operate
Low acoustics	Smooth steady combustion – no popping
Liquid, gas, or 2-phase	Can accommodate liquid, gas, and 2-phase, reduces unusable propellant

NOFBX™ SSTO MAV: In 2001, a NASA and Jet Propulsion Laboratory (JPL) commissioned industry study was performed to look at different MAV system design options. Several propulsion system options were studied including a two stage solid, a liquid NTO/MMH bipropellant, and a gelled propellant system [3]. These previous MAV studies had not included NOFBX™ monopropulsion systems as the NOFBX™ monopropulsion systems did not yet exist. The following NOFBX™ SSTO MAV design described below is a new and exciting option for future planetary ascent vehicles.

NOFBX™ SSTO MAV Point Design. Key system design features for a baseline NOFBX™ monopropulsion, SSTO MAV are summarized below:

- High performance single stage system capable of delivering a 5 kg Orbiting Sample (OS) into the required orbit
- Three 445 N (100 lbf) regeneratively cooled NOFBX™ thrusters derived from Firestar's Technology Readiness Level (TRL) 9 NOFBX-100 model
- A 3-cluster engine configuration with pitch and yaw control provided by differentially throttling individual engines, which eliminates the need for mechanisms and associated complexity
- Helium-over-liquid as a low complexity, low risk pressurization approach
- Composite Overwrap Pressure Vessel (COPV) tanks for significant mass reductions

Figure 1 shows a comparison of a resulting NOFBX™ SSTO MAV configuration with the NASA 2001-2002 2-stage solid rocket MAV. Note the increased usable volume and surface area in the NOFBX™ MAV over the 2-stage solid MAV, which enhances design flexibility.

Benefits of an NOFBX™ SSTO MAV. The baseline NOFBX™ MAV described above affords significant advantages over the original 2001 baseline MAV architecture, including:

- Inherently simpler overall MAV system design
- Only one propellant tank required, which increases the usable volume inside the MAV
- Eliminates upper stage, which greatly simplifies design and operational requirements
- Significantly decreased scope, complexity, cost, and schedule risk of pre-flight testing by avoiding multiple flight configurations
- Ascent trajectory optimization with restartable and deeply throttable propulsion system.
- Storability and operability over a wide temperature range.
- Mild human safety toxicity characteristics
- Less contaminating to the martian surfaced
- Fewer high-risk gimbals and other mechanisms by using differential throttling of fixed engines to provide vecor control
- Greater on-orbit vehicle surface area and internal volume.
- Potential for *in situ* propellant top-off
- Mitigation of critical challenges identified by the NASA Mars program (thrust vector control, propellant compability, pre-flight testing, sufficient development lead time).

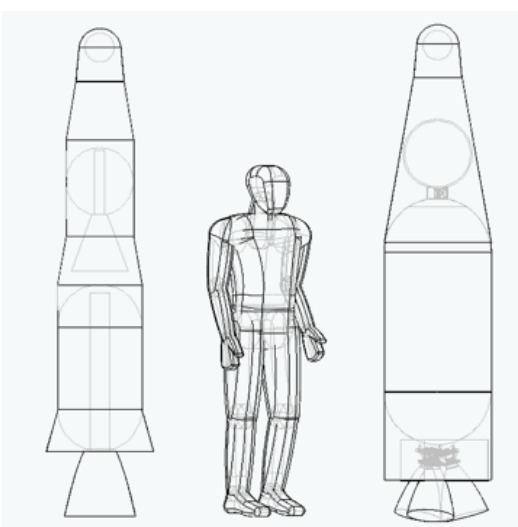

Figure 1. Left – NASA 2001-2002 two stage solid rocket MAV baseline. Center – average size person for scale. Right – NOFBX™ SSTO MAV

Summary: A liquid NOFBX™ monopropulsion SSTO MAV clearly presents many technical, operational, and programmatic advantages for the currently held MSR architecture. The point design presented above illustrates the NOFBX™ MAV's inherent simplicity, high performance, and flexibility, all of which translate to risk mitigation and cost reduction for MSR. We believe this SSTO ascent engine concept is an elegant, yet legitimate, approach to solving the technical challenges of designing, testing, and operating the MAV within the constraints of the MSR architecture.

References: [1] Mungas G. S et al. (2008) JPL Technical Report to Subcontract 1265181. [2] Mungas G. S. et al. (2010) JANNAF, May 2010 [3] Stephenson, D. D. (2002) *38th AIAA/ASME/SAE/ ASEE Joint Propulsion Conference & Exhibit*, July 7-10.