Adaptive Electric Propulsion for ISRU Missions

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In Situ Resource Utilization is a concept that is key to the success of future manned missions. The "5:1 concept", for Mars has shown that every 1 kg of mass saved on Mars through ISRU is the equivalent of 5 kg in LEO and 85 kg on Earth [1]. Using ISRU to provide propellant for propulsion systems is not a new concept. Several studies have been performed that show large gains if Martian atmosphere is processed to make Liquid Oxygen, Methane, or Hydrogen for traditional chemical systems [2]. Additionally, using asteroid, Lunar, or Martian water can also be immensely beneficial for solar and nuclear thermal propulsion systems [3]. In fact, the latest NASA Design Reference Mission Architecture 5.0 (2009) proposed a nuclear thermal rocket with ISRU [4]. However, ISRU propulsion studies to date have been limited to thermal and combustion systems and the low specific impulses that are associated with them. In order to increase payload fraction, electric propulsion having specific impulses of 2000-6000 seconds are required as will be shown with direct mission analyses. This is particularly important to Martian and asteroid cargo missions, where cost and payload fraction are driving factors, rather than trip time.

Traditional electric propulsion has been demonstrated to operate excellently on noble gases such as Xenon and Krypton. For propellant gasses that contain oxygen or volatiles, the primary failure mode for traditional EP is the rapid poisoning of the high-temperature neutralization cathodes. In addition, electrostatic thrusters have direct plasma-wall and plasma-electrode contact. This contact inevitably leads to erosion and high-temperature wall chemistry. If Oxygen, Hydrogen, or Carbon containing gases are passed through these thrusters there are significant detrimental effects including increased wall erosion, carbon deposition and, perhaps worst of all, the creation of conductive or partially-conductive layers on both insulating components and electrodes. It is clear that new technologies will be required to enable ISRU at higher specific impulses.

The singular ISRU-compatible electric propulsion system that has been investigated experimentally is an H2O Pulsed Plasma Thruster [5]. This groundbreaking research showed these thrusters to be both feasible and have dramatic mission benefits. However, PPT's typically have relatively low efficiencies and limited scalability to higher power levels. Compared to existing PPT technology, the ELF-160A thruster technology is a fully electromagnetic and electrodeless propulsion system that is easily scalable from 1 kW to 10 MW. The ELF thruster demonstrated operation on Nitrogen and Xenon at 50 Joule per pulse [6]. The EMP thruster demonstrated operation on Xenon and a Hydrazine simulant at 1 Joule per pulse and 1-5 kW average power [7]. The Xenon Plasma Liner Experiment [8] demonstrated RMF formation on both Xenon and Deuterium at greater than 400 Joules per pulse (400+ kW). The ELF-160A thruster program seeks to leverage these extensive Xenon thruster results, and the limited operating points on complex gases, and demonstrate a steady state, fully ISRU compatible electric propulsion thruster. Test results and thruster performance will be present as well as developmental work on plasma pre-ionizers for FRC, including a liquid water injector, and thermal tests of a steady operation 30 kW pulse power units for the RMF.

Reference

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