22 N HPGP Thruster Life Testing

Henry W. Mulkey
NASA Goddard Space Flight Center, Greenbelt, MD 20771

Wilhelm Dingertz
Bradford - ECAPS, Solna, Sweden

In the ever-changing paradigm of efficient and capable spacecraft design, scientific missions continue pushing the envelope enabling spacecraft subsystems to deliver effective solutions to meet challenging new mission/spacecraft needs. From an in-space storable liquid chemical propulsion perspective, monopropellant hydrazine has been, and continues to be, a dependable propellant with considerable flight heritage, a variety of engine thrust classes available from multiple vendors, with repeatable and reliable performance. Additionally, the space propulsion industry has learned to successfully handle hydrazine, its regulations, the safety protocols, the personnel protective equipment, and the unique training standards – all requisite for loading spacecraft propulsion systems with toxic hypergolic hydrazine. The question now arises as to "what is next for in-space chemical propulsion?" Further, with the evolution and concrete advancements in innovative in-space green propellant technologies, capable of providing realizable benefits to scientific missions, concern over the reliability and availability of this higher performing and safer to handle class of propellants is waning. As science missions move forward with the potential flight infusion of High Performance Green Propulsion (HPGP), NASA and its industry partners are working to address any gaps in system reliability, performance, or unique operational considerations.

Propellant technology that offers both higher performance and significant reduction in personnel hazards compared to hydrazine presents an attractive propulsion subsystem design opportunity. Increased propulsion subsystem performance can result in lower spacecraft launch mass, larger scientific payloads, or extended on-orbit lifetimes. Mission trades using green propulsion technologies have been documented on multiple NASA Goddard Space Flight Center (GSFC) mission classes, examining various parameters and requirements to support mission architectures in Low Earth Orbit (LEO), High Earth Orbit (HEO), geostationary, lunar, planetary, and Quasi-halo orbit around Sun-Earth Lagrange point (L2). The results of these trade studies show promising, attainable benefits. The perceived programmatic risk of flying a newer propulsion technology has, unfortunately, not outweighed the benefits to date. To take advantage of the improved performance and mitigate programmatic risk, HPGP engines must demonstrate life testing at higher propellant throughputs than have currently been demonstrated.

In an effort to proactively address the challenges with technology infusion into a risk-averse community, NASA and the Swedish National Space Agency (SNSA) outlined a collaborative Implementing Arrangement (IA) for the respective agencies to pursue increased HPGP technology maturation. This initial IA effort began in 2013, fresh off the heels of the successful PRISMA HPGP technology demonstration mission. The IA targeted objective is to reduce risk to potential future HPGP missions and fully characterize the LMP-103S propellant and associated engine performance. Over the past eight years, HPGP has flown in propulsion systems on twenty-five (25) spacecraft from seven (7) different Launch Ranges around the globe and on seven (7) different Launch Vehicles. Six (6) of these launches involved multiple loading operations for multiple spacecraft. For U.S. Range operations, nine (9) HPGP systems have been processed at Vandenberg Space Force Base (VSFB): six (6) in 2017, and three (3) in 2018. Six (6) more have been processed at Cape Canaveral Air Force Station (CCAFS) in May 2020, with three (3) systems launched in June 2020 and the remaining three (3) system were left loaded and ready until their launch in August of 2020. Three (3) more systems have been processed at Wallops Flight Facility (WFF) and launched in June 2021. In addition, these propulsion subsystems employed heritage propulsion subsystem component such as valves, filters, and pressure transducers, and have further demonstrated nominal functionality in both diaphragm and Propellant Management Device (PDM) propellant tanks. Based on these successes, HPGP technology continues to be considered for NASA Science Mission Directorate missions at GSFC.

The work presented herein represents many years of development and collaborative efforts to successfully align higher performance, low toxicity hydrazine alternatives into scientific missions. NASA GSFC Propulsion Engineering, in collaboration with Bradford ECAPS, has developed mission specific thruster design and testing requirements to establish GSFC's desired test conditions and firing sequences. In 2017, the first flight-like 22 N HPGP thruster Engineering Qualification Model (EQM-1) was designed and built by Bradford ECAPS to prove out the thruster design, materials, build process, and test campaign with respect to NASA GSFC critical component and mission requirements. This test program was developed to comprehensively test the thruster, the technology, and ultimately increase the 22 N HPGP Technology Readiness Level (TRL). EQM-1 was tested to environmental qualification levels prior to hot fire performance testing to represent the relevant end-to-end environment (launch to on-orbit operation) with required margin. This thruster demonstrated steady-state and pulse mode operational capability with propellant thruster throughput up to ~53 kg. At this throughput level, the EQM-1 engine began to present off-nominal performance and the test campaign was halted to allow for non-destructive testing and identify the root cause for the anomalous performance.

Capitalizing on the successful elements of the EQM-1 campaign, an upgraded 22 N HPGP EQM-2 has been manufactured by Bradford ECAPS to meet the complete GSFC requirements. The EQM-2 thruster's test campaign has further demonstrated the robustness of the HPGP propulsion technology and increased the Technology Readiness Level (TRL) by undergoing a full acceptance test program, then proceeding into qualification, including environmental testing (vibration and shock to qualification levels), as well as hot-fire life testing, operating at steady-state and pulse modes with increased propellant thruster throughput to ~150 kg. The HPGP thruster performance testing enables effective HPGP thruster readiness evaluation to meet NASA candidate mission requirements in the future.

Glamor Shot of Engine