DEVELOPMENT OF A MODULAR PROPULSION SYSTEM FOR USE IN A DEEP SPACE HYBRID ARCHITECTURE

BENCHMARK space systems

Background

With recent and upcoming initiatives to revisit the moon and to begin planning for sending humans to Mars, the role of small spacecraft to facilitate and compliment these types of missions continues to grow. However, unlike low-Earth orbit (LEO), where small satellites have historically found their highest utilization, venturing further away from Earth and the more benign space environment it provides can prove to be a challenge for spacecraft designers. Factors can become difficult to design for, such as expected temperature ranges, power generation and radiation effects. At the same time, the objectives that small spacecraft are attempting to accomplish are becoming more and more complex as the capabilities of these spacecraft continues to grow. One example of this increasing complexity can be found in Rendezvous and Proximity Operations (RPO) missions, where spacecraft attempt to perform tasks involving on-orbit servicing, docking, active debris removal, formation flying, inspection, or any other function that involves one or more satellites (natural or otherwise) matching their orbital plane, altitude and phasing while also performing maneuvers to approach at a close distance[1].

As the number of small satellite missions operating beyond LEO grow, so too will the need for spacecraft that are capable of performing complex RPO. One key technology that is needed to facilitate these types of missions is a means of propulsion that is capable, reliable, and safe to use and handle. Benchmark Space Systems is poised to provide the mobility solutions that will enable these deep space missions to traverse the vast distances as well as help carry out the precise maneuvers necessary for these types of endeavors. One such example is the RPO Kit that Benchmark Space has recently developed for a commercial customer, whose mission objectives will take their spacecraft to Cislunar orbit.

System Description

The current RPO Kit configuration is designed to be a bolt-on, turn-key modular propulsion system with five main components: an oxidizer tank, fuel tank, pressurant tank, modular avionics and 2N dual-mode thrusters. These and the associated fluid handling components (valves, pressure transducers, tubing, etc.) along with the system wiring harness is held together in a structural frame that allows for easy integration as a self-contained unit within the spacecraft bus for which it is intended. The RPO kit uses high concentration hydrogen peroxide (HTP) as a monopropellant and an oxidizer in combination with isopropyl alcohol (IPA) to provide two levels of thrust. Packaging has been optimized to provide the smallest possible envelope while also allowing for flexibility in the location and orientation of the thrusters. To provide a wide range of mobility solutions, the RPO kit has been designed in such a way that minimal non-recuring engineering is required to adapt the system to suit different operational needs. Alternative configurations are possible due to the ability to introduce tanks of different sizes as well as relocate or change the number of thrusters.

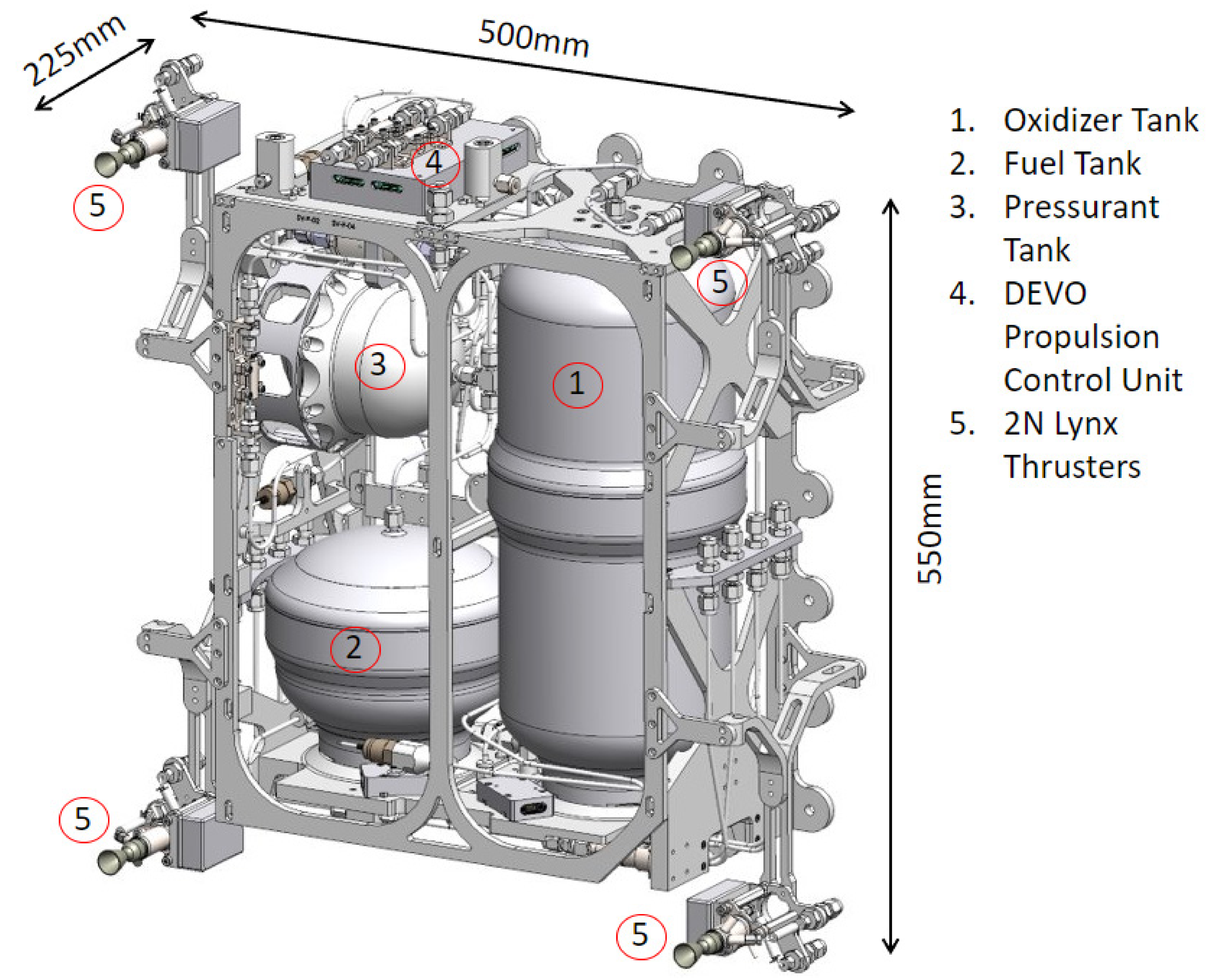

Figure 1: Major RPO Kit Components

Key Technologies

LOW COST / COTS COMPONENTS IN FLUID SYSTEM

Benchmark Space System's RPO Kit is a unique collection of technologies that are very suitable for facilitating both deep space missions as well as RPO. The following sections outline the key aspects of the RPO Kit's design that make it suitable for the type of missions discussed above.

HIGH PERFORMANCE NON-TOXIC PROPELLANT

In recent years, there has been a drive to replace more traditional propellants such as hydrazine with green alternatives. The term non-toxic or "green" refers to substances that are more environmentally friendly, easier and safer to handle, and help lower costs associated with storage and transport of the propellant[2]. Highly concentrated hydrogen peroxide (HTP) at 85% or higher concentration is being produced at industrial scale, and is regarded as a very promising alternative green propellant. In this bipropellant configuration that takes advantage of Benchmark's proprietary post-catalytic alcohol injection technique, HTP + IPA result in 20-30% better specific impulse than green and traditional monopropellants. As a monopropellant, HTP remains competitive in smaller spacecraft due to its impulse density, allowing for volume reduction compared with alternative or traditional monopropellants.

Despite its benefits and the fact that hydrogen peroxide has a long history of use in rocketry dating back to the 1940s, there are still lingering concerns about HTP that may make its use somewhat undesirable; namely HTP storability for long periods of time due to its autogenous decomposition into water and oxygen gas. While this decomposition does occur naturally, it is also accelerated by impurities in the HTP itself and in the materials used to contain and handle the fluid as well as higher temperatures. However, through intelligent material selection, proper cleaning and conditioning of liquid handling components and proper thermal control, HTP can be safely stored for extended periods of time with minimal need for venting of built-up oxygen gas[3].

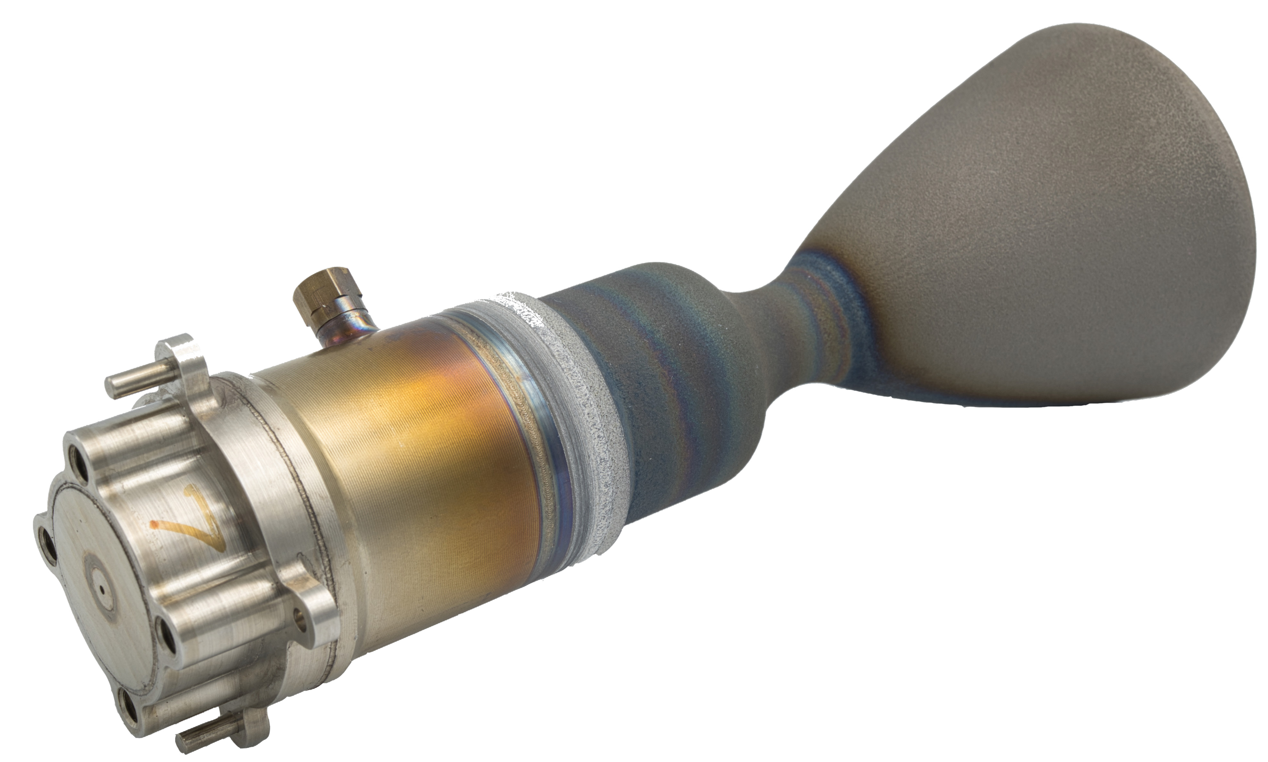

Figure 2: Dual-Mode HTP+IPA Bipropellant Thruster (Shown in 'Ocelot' 22N Size)

TANK MODULARITY

Modularity in Benchmark's RPO kit also comes from the growing array of storage tank sizes at its disposal. While the RPO Kit configuration discussed here utilizes a 0.6L pressurant tank and 1.8L and 5.9L fuel and oxidizer tank respectively, Benchmark can rapidly scale capabilities. With easily optimized ADM pressurant tanks, and concurrent development and qualification of a range of propellant bladder tanks from 0.5L to 33L to fill out a toolbox that can support cubesat through ESPA & OTV missions.

DUAL-MODE THRUST CAPABILITY

Benchmark's thruster technology provides a level of flexibility not commonly found in most propulsion systems. It allows for the ability to operate in both monopropellant and bipropellant modes using the same thruster assembly. In monopropellant mode, the HTP is run through a catalyst bed causing it to decompose into water, oxygen gas and heat. To operate in bipropellant mode, a fuel is injected downstream of the catalyst bed, utilizing the liberated oxygen gas and heat to initiate a combustion reaction for even greater thrust and efficiency. The ability to provide varying levels of thrust through the use of a single set of thrusters not only allows a single RPO Kit to fulfill the duties of both main engines intended for high delta-V maneuvers and RCS thrusters intended for low delta-V attitude control maneuvers, but it does so while minimizing mass through the elimination of redundant hardware. Furthermore, by utilizing adjustable brackets, thruster placement and orientation can be finalized late in the design cycle allowing for increased mission flexibility.

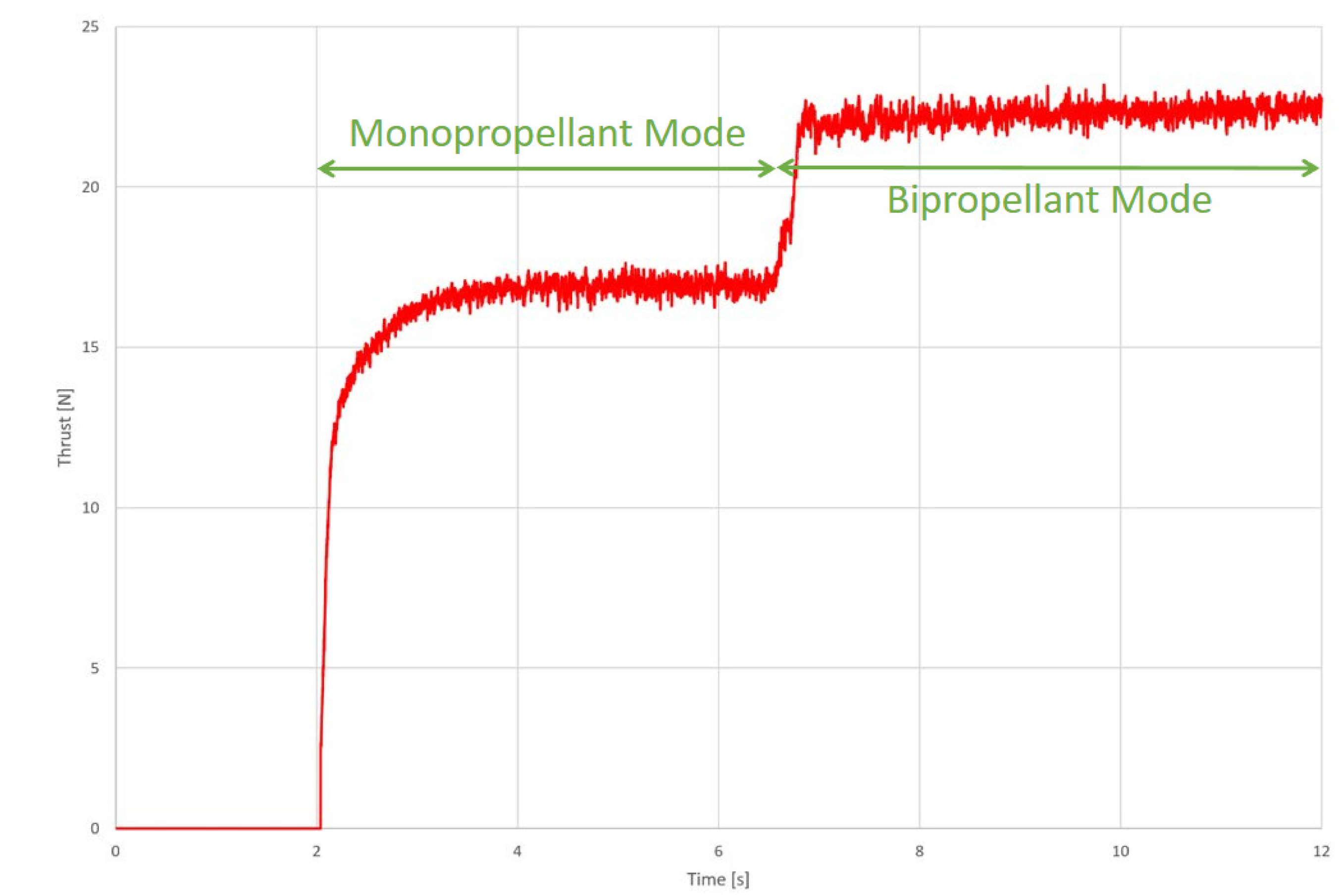

Figure 3: Sample Data from Thruster Characterization Tests (22N 'Ocelot' Thruster)

AVIONICS

The distributed electronics architecture of Benchmark's RPO Kit allows for rapid adaptation of avionics. The system provides a fast, safe, and cost-effective solution capable of utilizing COTS components and while withstanding near earth and deep space radiation. Benchmark is able to provide Integrated Evaluation Kits (IEKs) to interface with customer electronics before full system delivery, allowing for integrated testing prior to delivery of flight hardware. By leveraging existing physical printed circuit board assembly (PCBA) designs, the RPO Kit's avionics can accommodate any configuration of propulsion system, significantly reducing time from concept to delivery of single mission and multiple mission hardware.

1. Reesman, R., Rogers, A., "Getting in your Space: Learning From Past Rendezvous And Proximity Operations", The Aerospace Corporation, May 2018
2. "Green Propellant for Space Propulsion", European Space Agency, June 2001
3. Whitehead, J., "Hydrogen Peroxide Propulsion for Smaller Satellites", 12th AIAA/USU Conference on Small Satellites, 1998

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