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# Leveraging Existing EP Capabilities for the Emirates Mission to the Asteroid Belt

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# Abstract

The Emirates Mission to the Asteroid Belt (EMA), scheduled for launch in 2028, will conduct an eight-year, multi-target tour of seven main-belt asteroids, requiring over 10 km/s total delta-v and operations out to 3 AU. To meet these demands, the Laboratory for Atmospheric and Space Physics (LASP), in partnership with the United Arab Emirates Space Agency (UAESA), developed a Solar Electric Propulsion (SEP) architecture integrating two Safran Spacecraft Propulsion PPS®5000 Hall Effect Thrusters (HETs), a single Power Processing Unit (PPU), and Xenon Flow Controllers (XFCs) with a novel dual-pressure regulation strategy. The PPS®5000, originally developed for commercial use, has undergone extensive qualification and lifetime testing, demonstrating a cumulative impulse of 17.24 MN·s per thruster, throttling capability from 0.3 kW to 5 kW, and operational margins supporting EMA's power, xenon throughput, and lifetime requirements. The dual inlet-pressure XFC configuration enables precise flow control across the full thruster operating range while remaining within thermothrottle current qualification limits. System-level coupled tests confirmed full PPU–XFC–HET compatibility across the extended operating range and current environments. This heritage-unit based SEP system minimizes technical risk while delivering the efficiency, scalability, and flexibility required for EMA and future deep-space missions with similar high-delta-v needs.


# 1. Introduction

The United Arab Emirates (UAE) has rapidly expanded its role in space exploration, achieving a major milestone in 2021 with the successful Mars orbit insertion of the Emirates Mars Mission's *Hope* probe. Building on this momentum, and in alignment with the UAE National Space Strategy 2030 to foster scientific and technological advancement among future generations, the UAE Space Agency (UAESA) is now developing the Emirates Mission to the Asteroid Belt (EMA). Scheduled for launch in 2028, EMA will visit seven main-belt asteroids to deepen our understanding of the early solar system, the origins of water on terrestrial planets, and the potential for resource utilization within the asteroid belt [1].

To support the mission's demanding propulsion and trajectory requirements, including a high delta-v profile reaching up to 3 AU, the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder has designed a solar electric propulsion system, developed in partnership with UAESA, and specifically tailored to meet the needs of EMA.

The primary scientific objective of EMA is to investigate the origin and evolution of water-rich asteroids. The mission aims to determine where these bodies formed, how they relate to meteorite populations, and what their chemical composition reveals about the history of the main asteroid belt. Scientific investigations will include mapping volatile content and surface mineralogy, studying geological history and internal structure, and characterizing thermophysical properties. In parallel, EMA will assess the resource potential of these asteroids to support future in-situ resource utilization. The mission will also monitor solar energetic particles throughout its journey to contribute new insights into heliospheric dynamics [1].

# 2. Mission Trajectory

The EMA mission design features a complex interplanetary trajectory that includes three planetary gravity assists (Venus, Earth, and Mars), six asteroid flybys, and a rendezvous with a seventh target. This trajectory enables EMA to encounter a diverse selection of main-belt asteroids, including (623) Chimaera, (13294) Rockox, and (10253) Westerwald, as well as three additional objects: (88055) 2000 VA28, (23871) 1998 RC76, and (59980) 1999 SG6. Following an initial flyby of the seventh target, (269) Justitia, the spacecraft will conduct proximity operations at the final rendezvous target, allowing for refined navigation and detailed scientific observations at multiple orbital altitudes [1].

The full trajectory and cruise phase delta-v and propellant budgets, shown in Fig. 1 and Table 1, respectively, highlight the mission's propulsion requirements and the relative timing of major events.

Table 1
EMA cruise phase delta-v and xenon propellant budget [2]

| Thrust Arc | Delta-v (m/s) | Xenon Mass (kg) |
|---|---|---|
| Cruise to Earth | 1,155 | 152 |
| Thruster Characterizations | 71 | 9.9 |
| Cruise to Westerwald | 1,865 | 224 |
| Cruise to Chimaera | 483 | 58 |
| Cruise to Rockox | 956 | 109 |
| Cruise to Mars | 1,670 | 169 |
| Cruise to 88055 | 1,630 | 155 |
| Cruise to 23871 | 342 | 37 |
| Cruise to 59980 | 526 | 60 |
| Cruise to Justitia | 1,340 | 131 |
| **Cruise Phase Subtotal** | **10,003** | **1,104.9** |

# 3. Mission System Drivers

EMA relies on a high-efficiency Solar Electric Propulsion (SEP) system for all primary trajectory and proximity operations maneuvers. This architecture is complemented by a hydrazine blowdown system, which supports early Trajectory Correction Maneuvers near Venus, assists with momentum management, and enables safe mode recovery.

The mission's ambitious trajectory necessitates approximately 1,200 kg of xenon propellant over more than eight years to deliver nearly 10 km/s of delta-v, far exceeding the qualified maximum throughput of

most existing Hall Effect Thrusters (HETs). Standard 5 kW-class HETs are typically optimized for GTO/GEO applications, operating efficiently at fixed power levels between 3 kW and 5 kW. In contrast, EMA demands a flexible propulsion system capable of supporting a broad operating range from 1 kW to 5 kW to accommodate variable mission phases and power availability.

To address these requirements, candidate thruster technologies were evaluated with an emphasis on throughput capability, throttling flexibility, and heritage. This process identified the PPS®5000 Hall Effect Thruster as the most promising option. Although not originally designed for deep-space missions, this hardware has demonstrated capabilities that make it well-suited to this class of mission. The following section summarizes its performance characteristics and relevance to EMA's operational profile.

# 4. Thruster Performance and Applicability

Comprehensive testing performed by Safran Spacecraft Propulsion (SSP) across the mission's power range provides valuable insights into the PPS®5000's versatility, robustness, and suitability for EMA. The thruster was originally qualified to ten reference operating points to support a broader operating domain than typically required for traditional commercial missions (see Fig. 2). This wide domain enables flexible integration with variable power architectures, a key requirement for deep-space operations.

The PPS®5000's lifetime qualification exceeds the mission's requirements, with a demonstrated total impulse capability of 17.24 MN·s, supported by 19,460 hours of accumulated firing time and 974.5 kg of xenon throughput per thruster (Table 2). This qualified throughput nearly doubles that of previous high-capability thrusters, such as the SPT-140, which was qualified to 500 kg [3–4].

Table 2
PPS®5000 Cumulative Life Qualification Summary [5]

| Total Impulse (MN.s) | Total Hours of Operation (Hrs) | ON/OFF Cycles (#) | Total Xenon Throughput (kg) |
|---|---|---|---|
| 17.24 | 19,460 | 9,595 | 974.5 |

# 4.1. Mission Requirements for Thruster Life

A summary comparison between EMA's electric propulsion demands and the PPS®5000's certified capabilities is provided in Table 3. This comparison demonstrates that all key parameters, including power range, total impulse, and xenon throughput, are met with sufficient margins.

Table 3
Comparison of EMA EP System Requirements vs PPS®5000 Qualified Performance

| Parameter | EMA Mission Requirement | PPS®5000 Capability |
|---|---|---|
| Power Range | 1-5kW | 0.3-5kW |
| Total Impulse (two thrusters) | 22.4 MN.s | 34.4 MN.s |
| Xenon Throughput | Up to 1250kg | Up to 1949 kg |
| Thrust/Isp Performance | Varies by phase | Meets Requirement |

A detailed review of the PPS®5000 lifetime qualification campaign confirmed that EMA's planned operational profile is well within the bounds of certified performance. The qualification campaign includes a 50% margin on total impulse, providing ample buffer to accommodate potential variations in wear rates or operational conditions over the course of the mission.

The qualification testing strategy was intentionally designed to conservatively envelope a wide range of operating points. Following the standard rule of thumb that wear mechanisms are bounded by the highest qualified power at a given discharge voltage, operation at 300 V is fully covered by OP5 (5 kW, 300 V), while operation at 375–400 V is encompassed by OP8 (4.5 kW, 375 V). Lifetime testing was split approximately evenly between OP5 and OP8, ensuring that wear mechanisms associated with both low- and high-voltage regimes were thoroughly exercised [5]. EMA's expected usage, with roughly half of the mission in the 300 V regime and half in the 375–400 V regime, is therefore fully encompassed within the demonstrated qualification envelope.

Additionally, SSP has observed no unexpected or voltage-specific degradation modes across these conditions. While minor differences in wear rates between voltages may exist at constant power, long-duration testing to date has revealed no measurable divergence in overall lifetime or erosion behavior [5]. This consistency supports the conclusion that the certified qualification envelope, with its built-in margin, provides high confidence that EMA's thruster performance will remain stable and predictable across the full mission duration.

# 4.2. Nominal and Extended Power Range Performance

In its mission-relevant power range of 1 kW to 5 kW, the PPS®5000 has demonstrated thrust levels from 51 mN to 290 mN and specific impulse values ranging from 1231 s to 1975 s (Fig. 3) [5]. This wide performance envelope enables propellant-efficient maneuvering during both higher- and lower-power cruise phases and proximity operations, even at reduced solar flux levels at distances up to 3 AU. The ability to deliver adequate thrust across this range is essential for deep-space missions requiring continuous trajectory shaping and flexible power allocation.

While high-power performance defines the cruise-phase capability, EMA's trajectory also includes extended periods with reduced available power, particularly at greater heliocentric distances. To ensure

continuous thrusting during these phases, the PPS®5000's low-power behavior was characterized to confirm stability, efficiency, and predictable performance across the full mission envelope.

## 4.3. Low-Power Characterization and Adaptive Operation

Additional short-duration test campaigns characterized the PPS®5000's low-power performance across a range of wear states, simulating conditions expected during mission phases with limited power availability. These tests demonstrated stable operation from 2 kW down to 0.3 kW, with predictable efficiency, reduced current oscillation amplitudes, and effective performance at low flowrates and current levels. This confirmed the thruster's ability to function reliably across a wide power spectrum. Notably, the thruster maintained stable discharge and efficiency using a fixed cathode-to-anode flowrate split ratio over the entire extended operating domain (Fig. 4), eliminating the need for additional cathode flow adjustments at low power [5].

In parallel with performance mapping, a review of potential degradation modes was conducted to assess whether extended operation at low power could influence thruster lifetime. This evaluation is crucial to ensuring the PPS®5000's certified margins remain valid over the mission's full eight-year operational period.

## 4.4. Failure Mechanisms

This thorough review of credible failure mechanisms indicated that extended operation at reduced power levels does not degrade the thruster's total impulse capability over its qualified lifetime [5]. This combination of low-power adaptability, stable performance, and proven qualification margins makes the PPS®5000 a high-performance and low-risk solution for long-duration, propellant-constrained missions such as EMA.

To further ensure long-term reliability and justify mission extensions or off-nominal operations, the PPS®5000 program also implemented an extensive cathode life testing campaign. Multiple qualification and flight-standard hollow cathodes were operated under varying throttling and cycling profiles, with some subjected to Destructive Physical Analysis (DPA) to identify and characterize wear modes. These tests confirmed robust performance across all profiles, including operation with oxygen-contaminated xenon, and supported lifetime modeling, material equivalence qualification, and process validation. Cathode CD024, tested extensively both in thruster and stand-alone modes, was successfully re-coupled with the EQM1 thruster at the end of the qualification program, demonstrating preserved functionality after prolonged use [5].

With thruster performance and life capability validated, attention shifted to integrating the electric propulsion system into a single-string spacecraft architecture to minimize mass, complexity, and power system overhead while meeting mission reliability requirements. This required careful coordination between power processing, xenon storage and delivery, and mechanical gimbaling to maintain precise thrust vector control.

# 5. System Description

# 5.1. EP Overview

To implement EMA's EP system approach in a cost-effective, single-string configuration, the system integrates a single PPU, two XFCs, and two PPS®5000 HETs. Power generation across heliocentric distances from 1 AU to 3 AU is provided by two 20-kW solar arrays paired with a 100 V regulated power bus. As shown in the Electric Propulsion System Block Diagram (Fig. 5), the PPU delivers regulated electrical power from the spacecraft main power architecture, conditioning it to support a thruster discharge operational power range from as low as 1 kW up to 5 kW. The PPU contains an internal switching unit which allows selection between the two HETs.

# 5.2. Xenon Propulsion System

The Xenon Propulsion System Pneumatic Block Diagram is presented in Fig. 6. A single composite overwrap pressure vessel (COPV) provides storage for up to 1,250 kg of xenon at a maximum launch pressure of 1,250 psia (8.6 MPa). Two fill/drain valves provide access for ground testing and propellant loading operations. The Pressure Management Assembly consists of two independent circuits, each with two latch valves in series for propellant isolation and a single-stage mechanical pressure regulator. Pressure transducers provide redundant state-of-health monitoring both at the tank and at the regulated pressure outlets. Downstream, the flow splits to the two XFCs providing the necessary inlet pressure. The XFCs consist of an inlet filter and two in-series solenoid valves, providing flow isolation. Finer flow regulation is performed by controlling the current to the thermothrottle. Two orifices or flow restrictors within each XFC provide the appropriate cathode-to-anode flow ratio to the HETs. The HETs are also mounted on gimbal platforms which provide thrust vector control.

The design relies on compatible, flight-qualified units for the HETs, XFCs (Fig. 7), and the PPU. To mitigate development and schedule risks, the project's objective was to use proven flight hardware wherever possible. This was especially important because the PPU performs closed-loop control of the XFC's thermothrottle current to regulate xenon flow to the thruster. To support this control architecture, it was necessary to retain the existing XFC thermothrottle design and control interface.

# 5.3. XFC Impacts

The XFC's flow regulation capability depends primarily on inlet pressure, reference temperature, and the applied thermothrottle current. The electrical current *I*_tt governs the amount of heat transferred to the xenon gas, which affects gas viscosity due to its temperature dependence and, in turn, modifies the Reynolds number. As a result, increasing *I*_tt raises the capillary temperature and reduces the xenon flow rate; conversely, decreasing *I*_tt reduces capillary temperature and increases xenon flowrate [7]. Figure 8 illustrates how the typical XFC flow rate varies with thermal and inlet pressure setpoints across the full range of input current, enabling a broad flow capability [6].

A key challenge in operating across the full 1 kW to 5 kW power range is the need to approximately double the typical XFC flow rate range provided by a single inlet pressure setpoint. This wide dynamic range must be met while staying within the bounds of qualified thermothrottle current settings. To address this, the proper selection of XFC inlet pressure was found to be critical. EMA collaborated with SSP to identify and characterize two inlet pressure setpoints capable of supporting the required expanded flow range while maintaining compatibility with flight-qualified thermothrottle operation [3]. Figures 9 and 10 illustrate the concept and demonstrate that the two inlet pressure setpoints encompass the desired mass flowrate range throughout EMA's expected operating-temperature range. These results formed the basis for adopting a dual inlet pressure strategy that balances technical performance with cost and risk considerations.

Implementing dual inlet pressures required an extensive trade study to assess architectural changes that could meet flow rate requirements while minimizing technical risk, cost, and schedule impacts. The selected approach, using a dual-setpoint mechanical regulator, offered a unique, cost-effective, and simple solution to support the full flow range. This decision was validated through a recently completed PPU–XFC–HET coupling test, which confirmed critical system compatibility across the extended operating domain and demonstrated that the XFCs, under closed-loop PPU control, can reliably deliver the required flow rates when supplied by the Pressure Management Assembly's dual-regulator setpoint design.

The combination of a high-performance thruster, precise xenon flow control, and flight-qualified SEP units provides a complete solution to EMA's propulsion challenges. System-level validation efforts have confirmed hardware compatibility and stable operation across a range of thermal conditions, flow rates, and power levels. These results demonstrate that the propulsion system is ready to support EMA's dynamic mission profile, including its extended cruise and proximity operations. The integrated design balances innovation with heritage hardware, providing a reliable foundation for deep-space missions with similar technical constraints and performance goals.

# 6. Conclusion

The Emirates Mission to the Asteroid Belt (EMA) demonstrates how a flight-qualified Hall Effect Thruster system can be adapted to meet the demands of a long-duration, high-delta-v interplanetary mission. The PPS®5000-based EP architecture, with its extended throttle range and validated dual-pressure xenon flow control, offers a low-risk, high-performance approach that balances capability, cost, and operational simplicity.

This work underscores the value of collaborative development, exemplified by the partnership between LASP and the UAE Space Agency, and the role of rigorous ground validation in reducing mission risk and expanding the reach of electric propulsion. EMA's electric-propulsion and xenon-management systems form a proven blueprint for deep-space missions with high delta-v and variable power requirements. The

experience gained will fuel the development of scalable, adaptable solar electric propulsion architectures that open new frontiers for science, logistics, and resource utilization across the solar system.

# Abbreviations

| Symbol | Definition |
|---|---|
| A | amperes |
| AU | astronomical unit |
| hrs | hours |
| I_d | discharge current |
| I_tt | thermothrottle current |
| kg | kilogram |
| km/s | kilometers per second |
| kW | kilowatt |
| mN | millinewton |
| MN·s | meganewton seconds |
| MPa | megapascal |
| m/s | meters per second |
| mg/s | milligrams per second |
| psia | pounds per square inch absolute |
| s | seconds |
| U_d | discharge voltage |
| V | volts |
| W | watts |

# Declarations

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**Competing interests:** The authors have no relevant financial or non-financial interests to disclose.

**Data availability:** Not applicable.

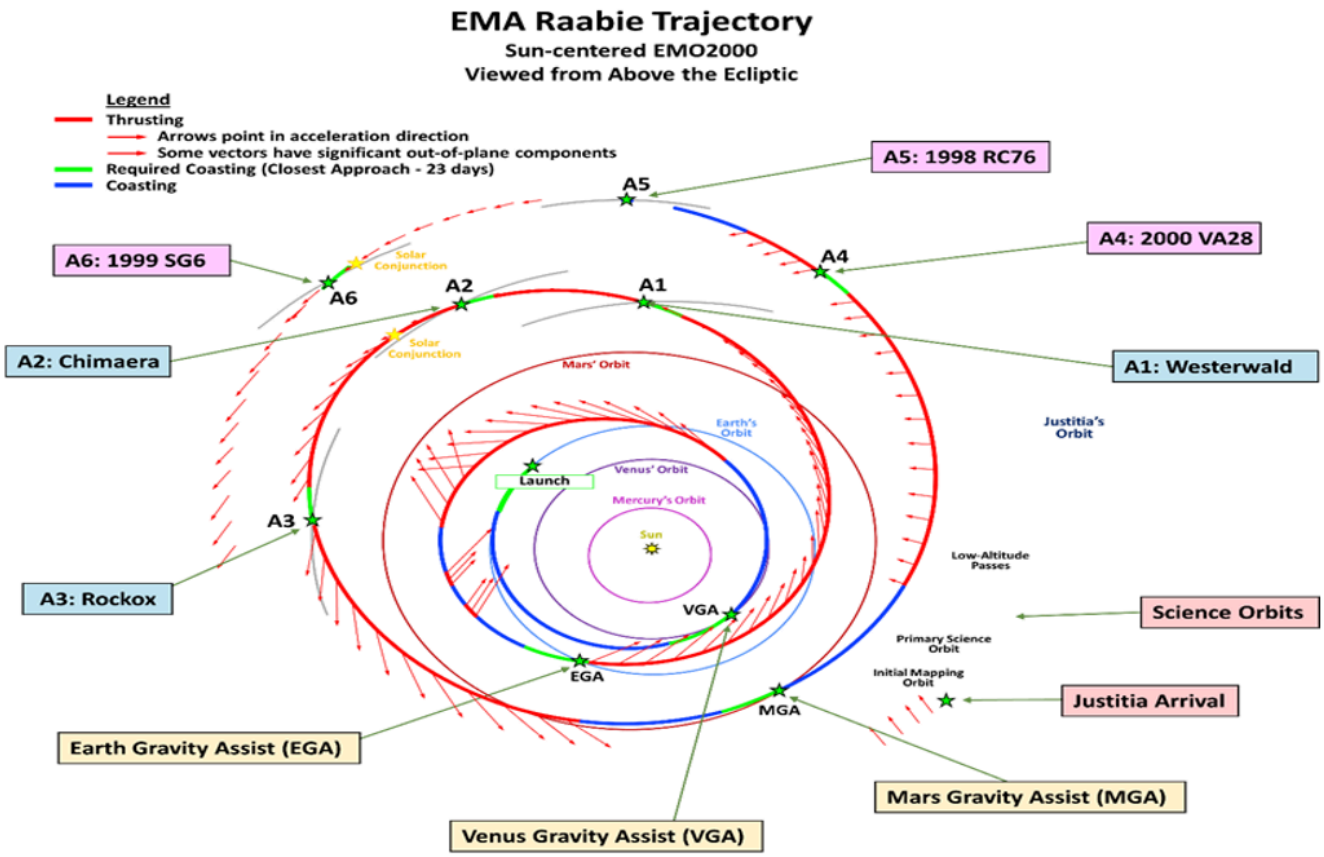
**Code availability:** Not applicable.

**Authors' contributions:** S. Green led propulsion systems engineering and manuscript preparation. B. Reese contributed to spacecraft systems management and manuscript review. R. Riley contributed to electrical power systems analysis and manuscript review. M. Alhammadi contributed to xenon propellant analysis and manuscript review. M. Al Ameri contributed to spacecraft management and manuscript review. O. Duchemin provided thruster qualification data and contributed to manuscript review. All authors read and approved the final manuscript.

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# Figures




## Figure 1

EMA Mission Flight Trajectory

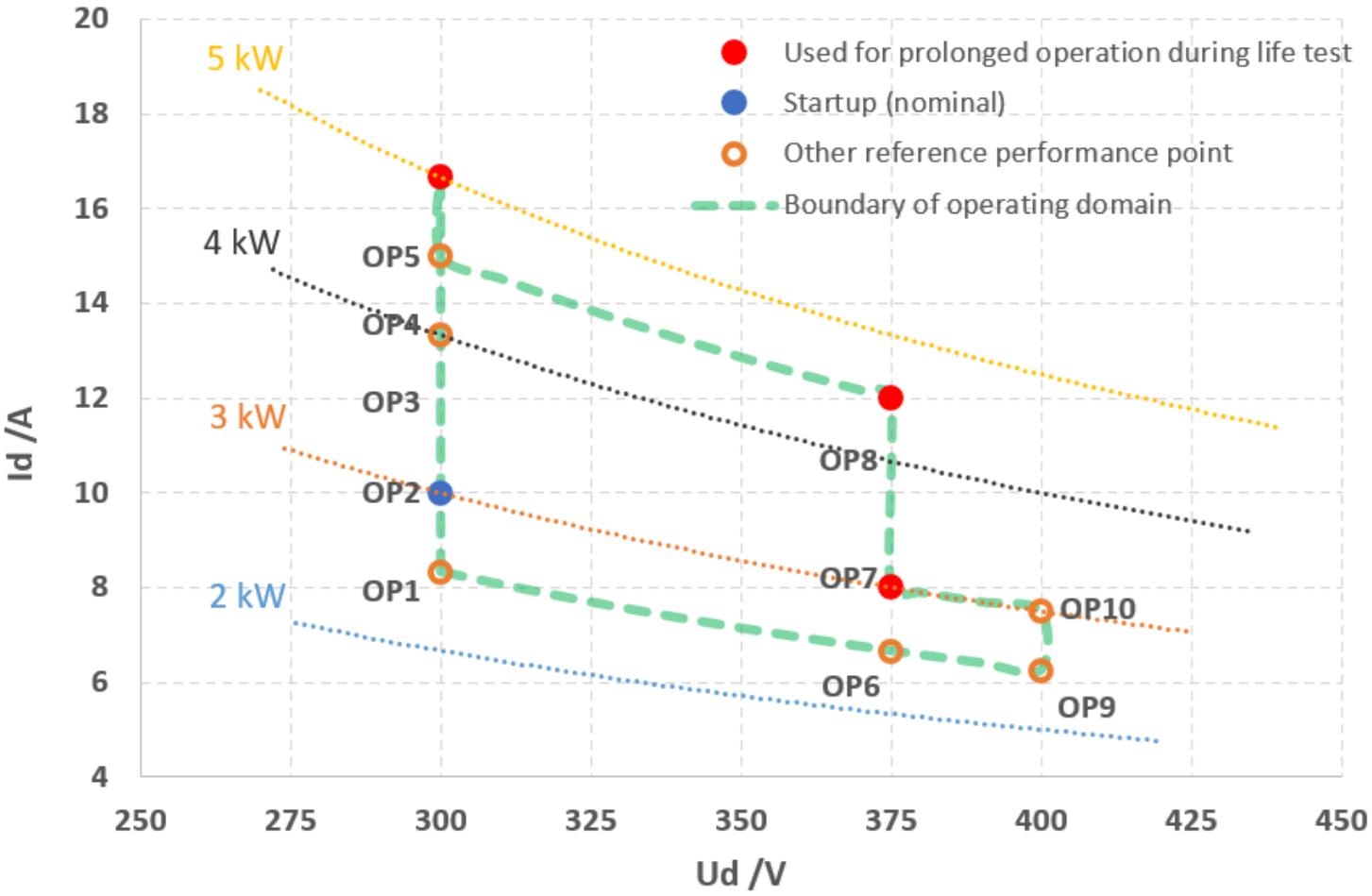
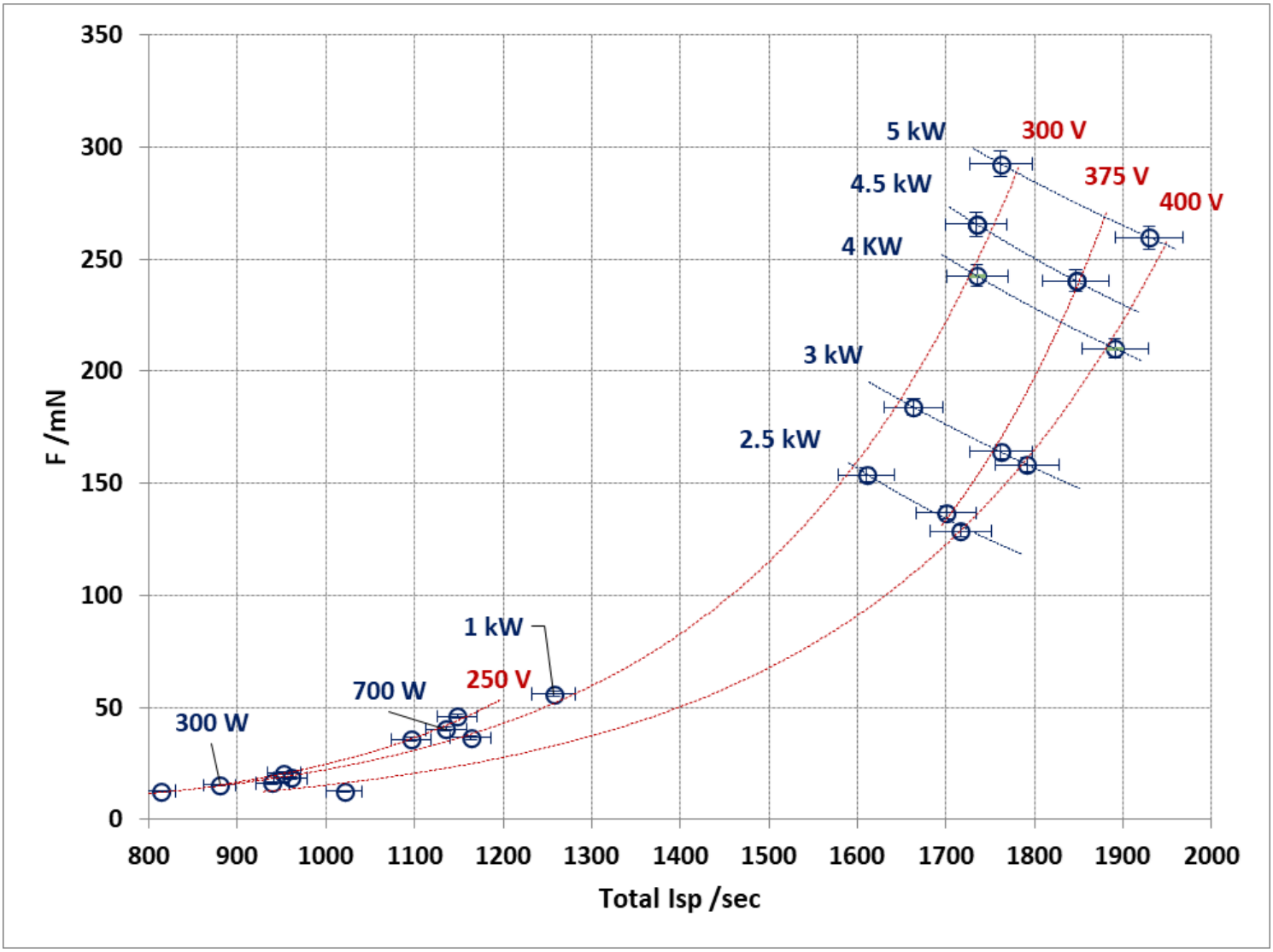



**Figure 2**

PPS®5000 qualified operating domain [5]




## Figure 3

PPS®5000 performance at BOL over extended range [5]

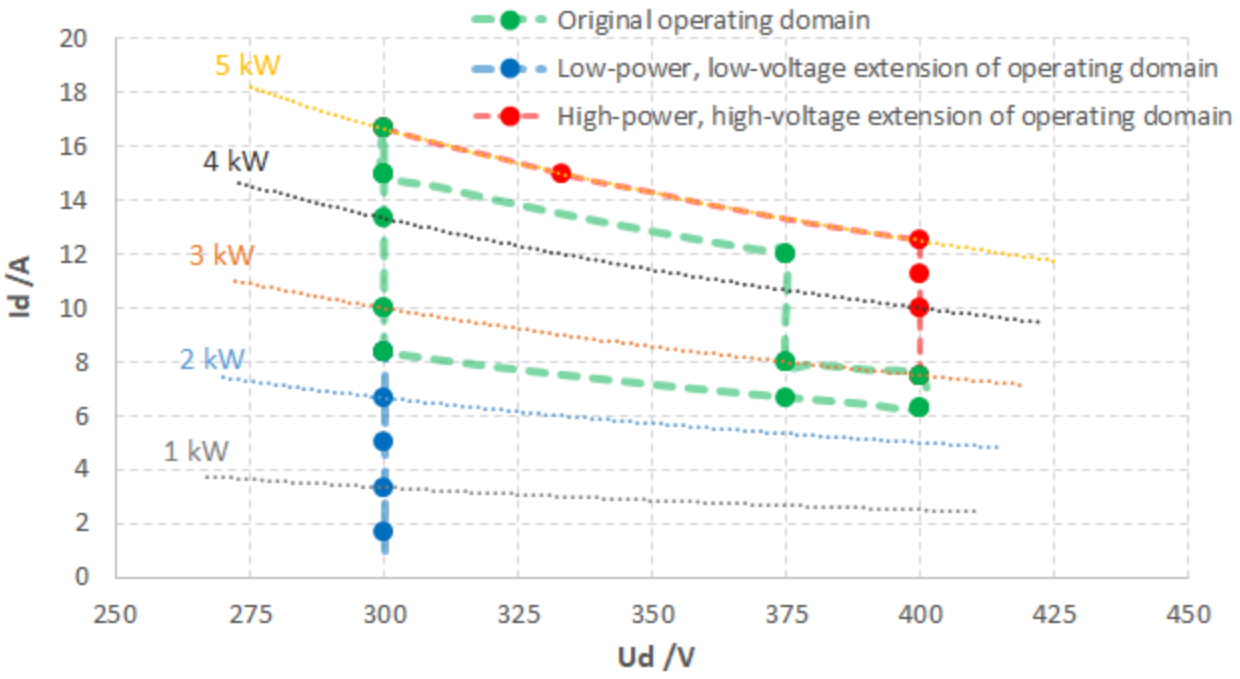



**Figure 4**

Extended PPS®5000 operating domain [5]

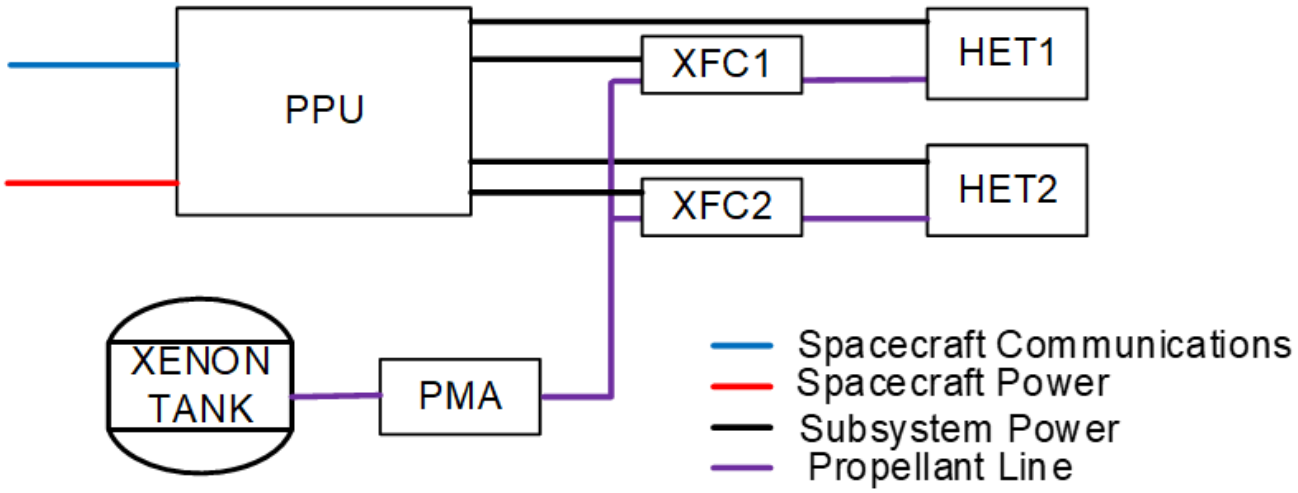
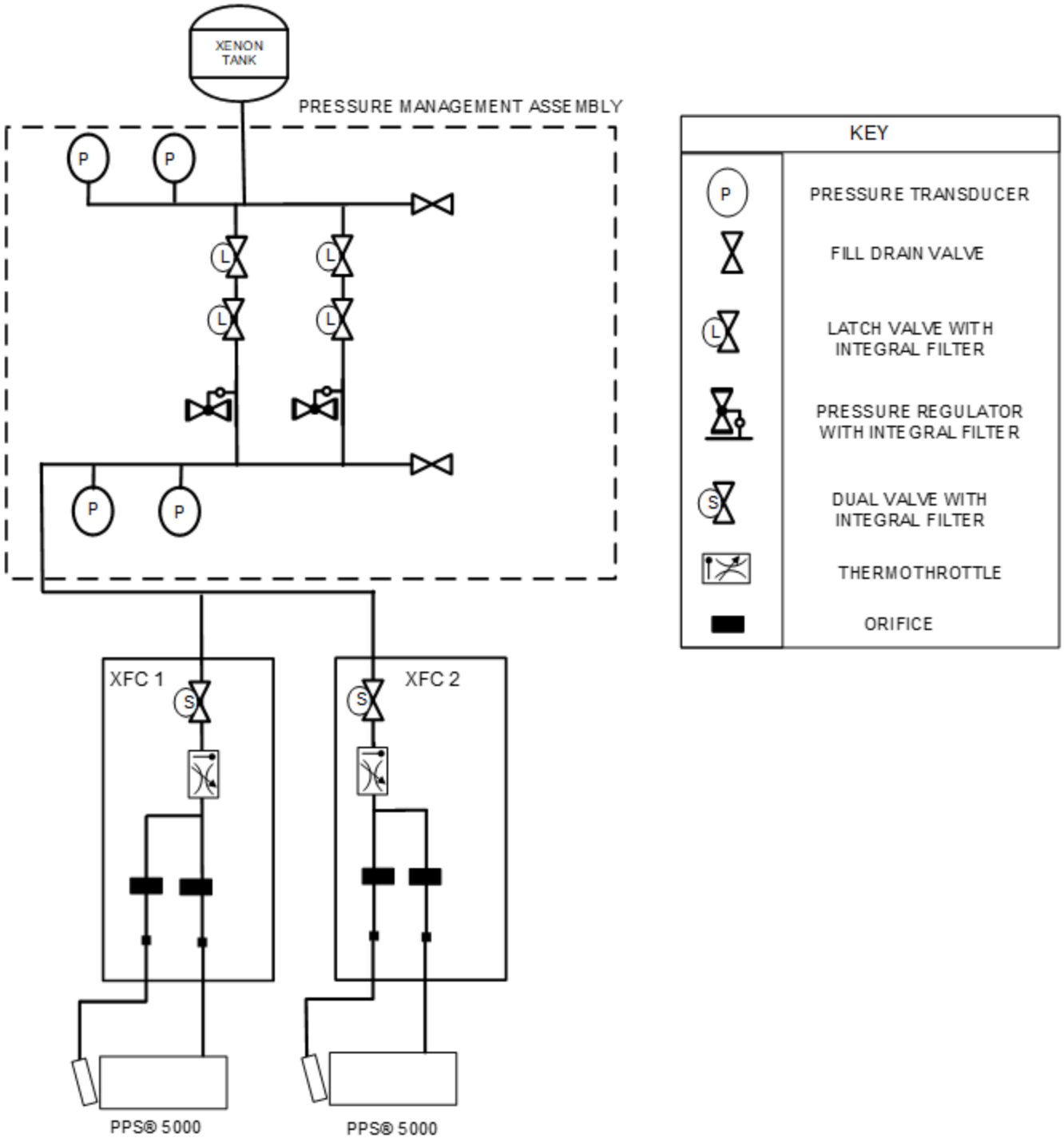


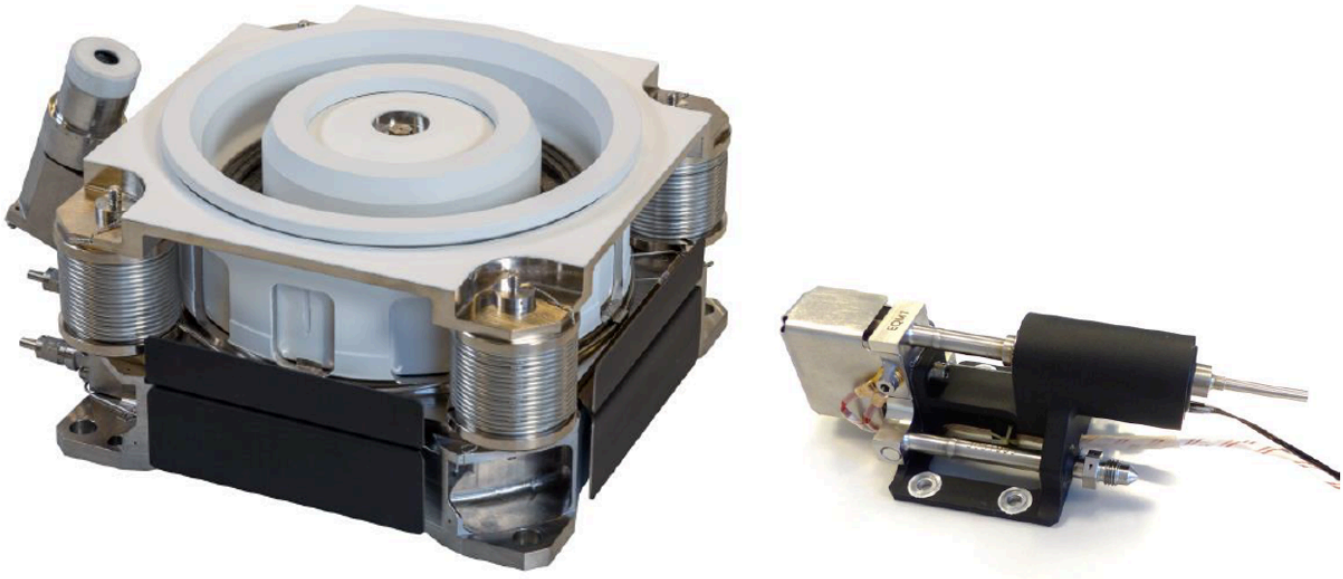

**Figure 5**

Electric propulsion system block diagram



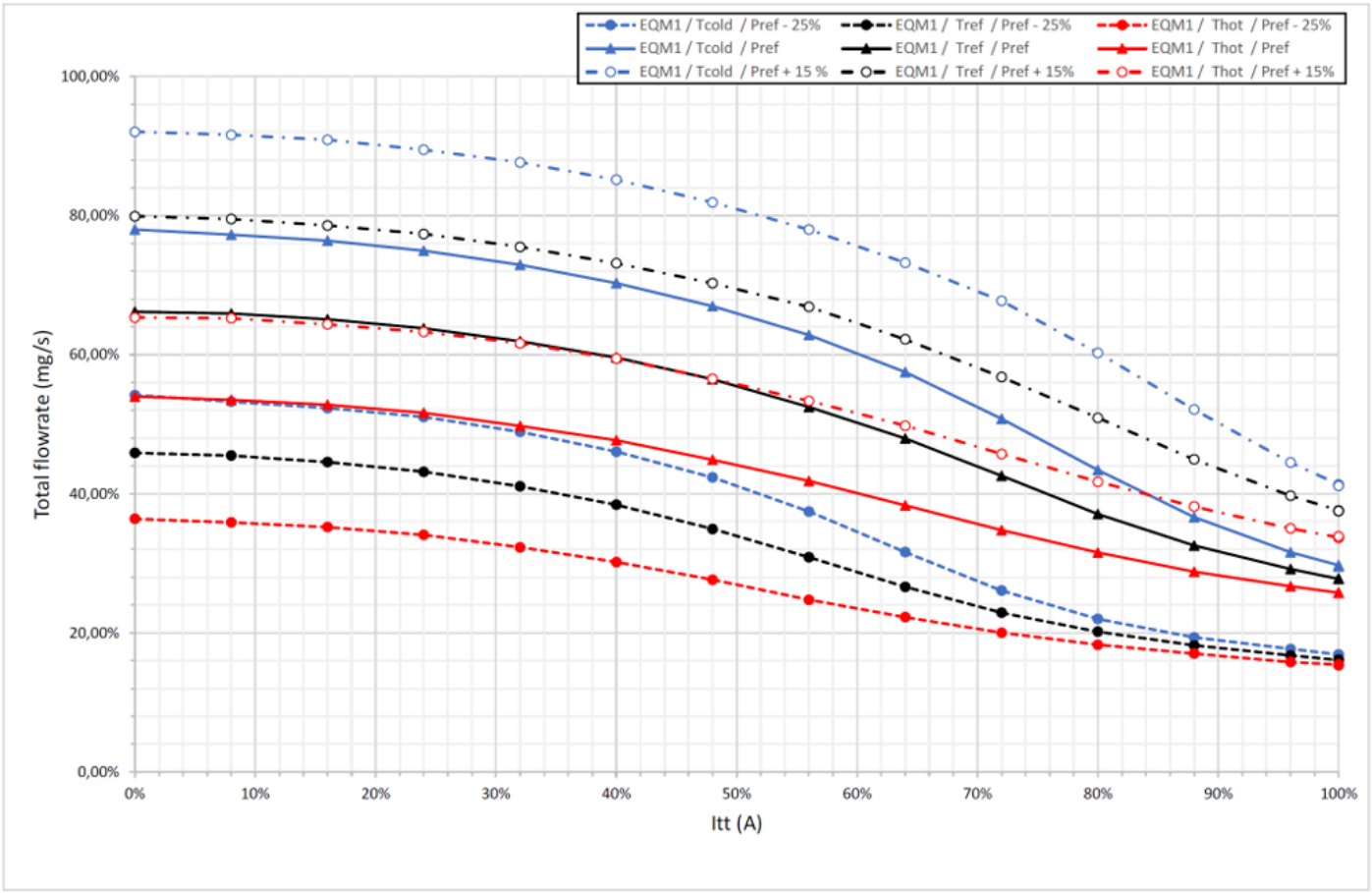

## Figure 6

EMA electric propulsion system pneumatic block diagram



## Figure 7

PPS®5000 Hall Thruster Unit (a) and XFC-5000 (b) [6]




## Figure 8

Typical XFC flowrate as function of thermothrottle current [6]

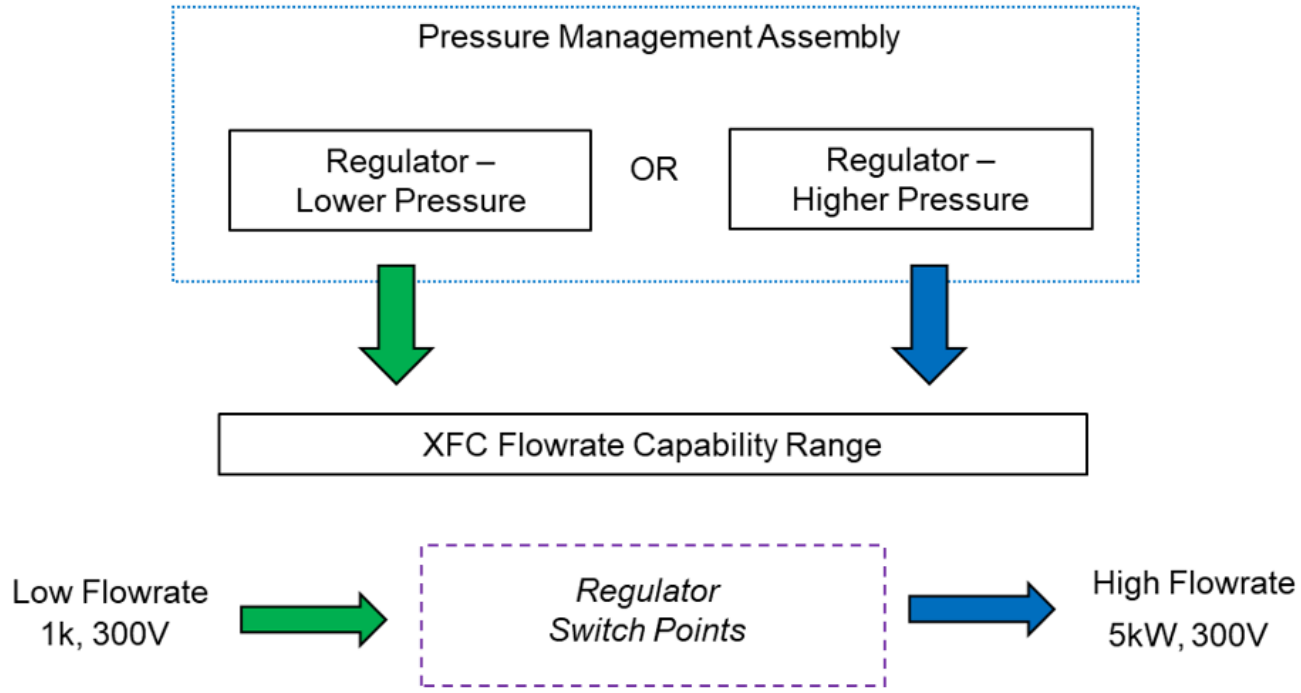
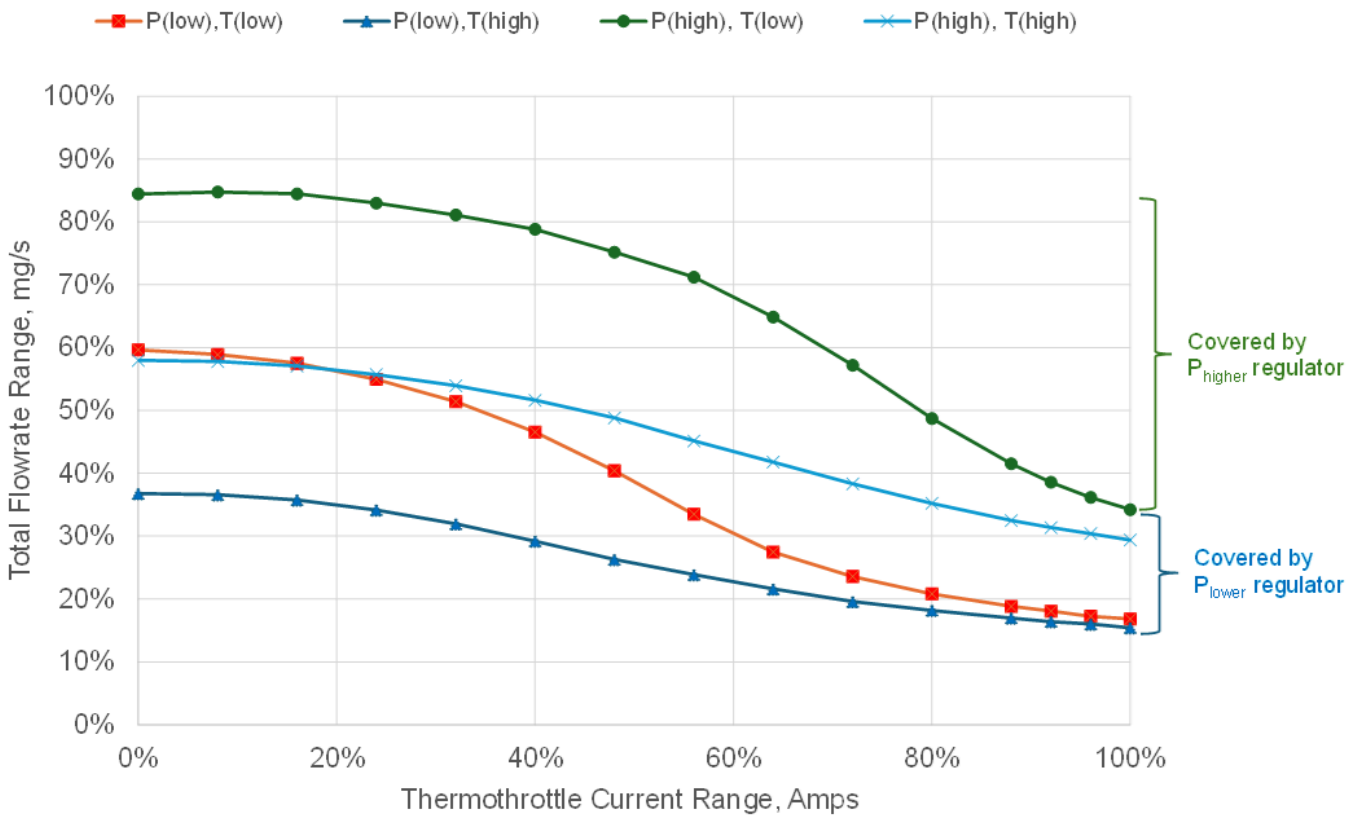



**Figure 9**

Dual pressure setpoint concept



## Figure 10

EMA XFC flowrate characterization testing