

HYBRID PROPULSION SYSTEM FOR DEEP SPACE CUBESAT MISSION

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ABSTRACT:

There is currently a clear trend towards larger and more capable CubeSats [1], where highly advanced missions include autonomous formation flying, rendezvous and docking, inspector spacecraft, and interplanetary missions. These CubeSat missions require sophisticated propulsion systems, but also other aspects such as autonomy and reliability become crucial.

As part of the ESA M-ARGO mission such a system is being developed. This system contains components of varying TRL that are assembled and tested to validate the approach of having a combined cold gas (CG) and electric propulsion (EP) system.

The main focus of this paper is to describe the progress of the ongoing development of such a propulsion system. The paper will describe the propulsion system itself and then focus on the testing of parts of the system.

1. INTRODUCTION

Deep space CubeSat missions such as M-ARGO is the ultimate arena where challenging mission requirements meet the limitations of CubeSats. Nowhere is this as clear as in the propulsion system. Demands on high total impulse as well as 6 degrees of freedom control, while fitting into a small CubeSat formfactor creates novel challenges for all involved parties.

The Xenon based Hybrid Propulsion System (HPS) is developed in an activity where the goal is to create and test a breadboard that combines the required components for such a system.

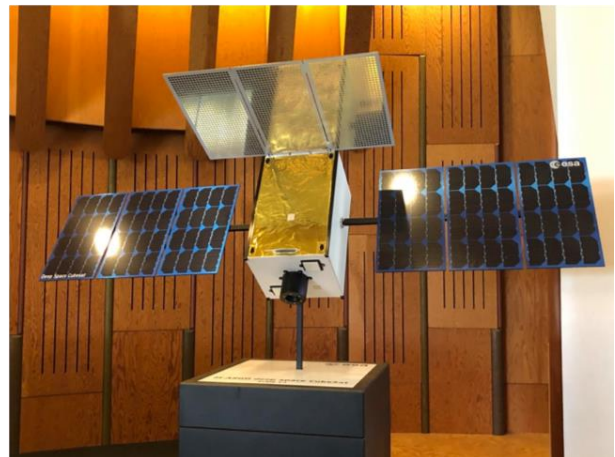


Figure 1. M-ARGO satellite mockup at ESA ESTEC

Due to the complexity of the HPS, it was decided in this activity to go with a system architecture that was flexible when it came to resources and scheduling. Setting up Flow Ground Support Equipment (FGSE) / Electrical Ground Support Equipment (EGSE) for the tests is a labor-intensive task and it requires procurement of several long-lead items. On top of this, the process of qualifying the setups themselves requires time. Further, several teams from different countries were working on the different parts of the system creating an even more complex puzzle to solve. To avoid scheduling issues and to make the testing as focused as possible it was decided to perform the testing of the cold gas parts and the electric propulsion parts of the HPS separately. This meant that a coupling test of the EP thruster, PPU and flow control system was performed at the ESTEC lab to verify the performance of the electric propulsion part of the system. Gomspace in Sweden would separately set up a capability to perform cold gas high-pressure testing at their facilities in Uppsala in accordance with the requirements on the system.

2. HPS DESCRIPTION

The HPS is a propulsion system specifically developed to meet the demanding requirements of

a deep space CubeSat mission. It consists of a set of key components that are divided into two segments for the breadboard testing phase. Those segments are the Cold Gas segment and the Electric Propulsion segment. These segments are individually connected to a high-pressure Xenon storage/feed.

2.1. Cold gas segment

The cold gas segment of the HPS consists of a high-pressure isolation valve followed by a mechanical pressure regulator used to regulate the Xenon stored at roughly 120 bar MEOP down to a pressure of around 2 bar. The Xenon is then distributed to 12 thruster assemblies (including thruster valves) produced by Gomspace Sweden. For the breadboard testing only 4 thrusters will be used since it is the maximum amount of thrusters expected to fire simultaneously. The thrusters are miniaturized 1mN thrusters and they are controlled by a propulsion control board. A relief valve is required as part of the cold gas segment to make sure damaging over-pressure is mitigated. The relief valve will not be a part of the breadboard.

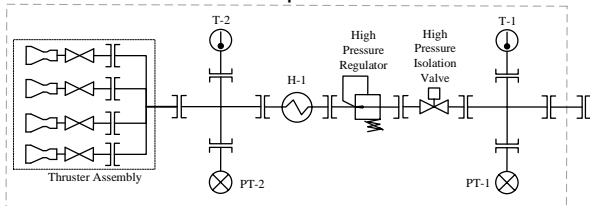


Figure 2. Cold gas segment for the breadboard testing

2.2. Electric propulsion segment

The electric propulsion segment of the HPS consists of three major components:

- The RIT3.5 EP thruster from IMS Space Consultancy
- The custom developed PPU from ASP
- The Flow Management System (FMS) from Bradford Engineering

Here the FMS simply provides a stable flow of Xenon to the EP thruster while the PPU provides power and control to the thruster.

In order to comply to the M-argo requirements – covering not only overall system performances but also extremely strict power and mass budgets - intensive trade-off exercises have been concurrently carried out in the course of the project that highlighted main design adaptations necessary for the thruster head itself and features required from sub-systems to support the final EP configuration.

All the components have then been compiled and tested at component level before being assembled into a system level setup.

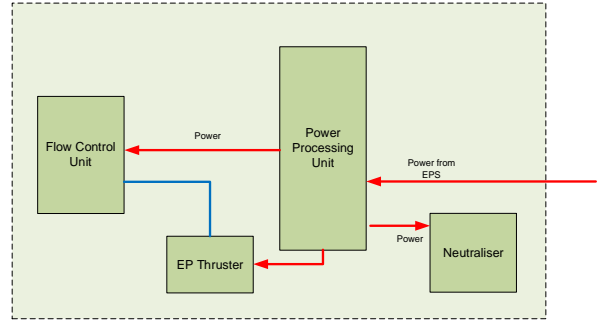


Figure 3. Electric propulsion segment architecture

3. TEST SETUP

3.1. Cold gas test setup

Cold gas testing will be performed on component level before proceeding to the system level breadboard testing. The testing at system level will be conducted at Gomspace Sweden’s cleanroom facilities.

The breadboard will be placed inside a large Thermal Vacuum (TVAC) chamber to be able to simulate the conditions experienced in space and the system will be tested as expected during flight. This will give an indication of what difficulties arises from the architecture and design chosen.

The test setup also includes FGSE and EGSE. The challenge when it comes to the FGSE is the high pressures required to be fed to the breadboard as well as the stability of that feed. The EGSE is mainly needed for reading out data from the components as well as the controlling heaters/sensors within the system and making sure the environment around the breadboard is as intended.

3.2. Electric propulsion test setup

The test setup was determined to support the main objectives of the current project for the EP segment testing:

- Verification of the component performances;
- Verification of the interfaces between the components;
- Verification of the coupled EP performance.

While the PPU and the FMS have been preliminary tested at the corresponding developer premises, for the RIT3.5 thruster component level test was integrated in the test sequences of the test campaign performed at ESA EPL and was supported by EGSE and FGSE provided by ESA TEC-MPE team.

The test was then sequenced to confirm the thruster performances first with the EGSE and the FGSE and then consequently swap to the FMS and then the PPU coupling.

The test has been performed in the Gigant vacuum

test facility with 1.6 m diameter and 2.5 m length and total pumping capacity of around 53 400 L/s (Xe) [2]. Equipment including RIT3.5 thruster, Radio Frequency Generator (RFG) (for EGSE configuration), FMS (for coupling sequence) and all the internal cabling and piping have been fit on the moving trolley within the smaller facility hatch isolated from the main chamber by the gate valve. After the pumping cycle was performed, the trolley would be moved towards the main facility volume as far as the piping would allow.

The EGSE, FGSE and FMS control units were located close by the facility hatch allowing to minimize necessary interfaces. However, in order to simulate the distance between the thruster head and PPU not exceeding that expected for the M-ARGO satellite, it was necessary to locate the PPU directly on the facility flange.

4. RESULTS

4.1. Cold gas results

The cold gas testing is still at component level and not ready enough to present any results. A significant test campaign for the cold gas part of the HPS is currently ongoing and will continue during fall of 2022.

4.2. Electric propulsion results

The EP system coupling test campaign has been performed throughout Q3-Q4 of 2021 in ESA ESTEC EPL.

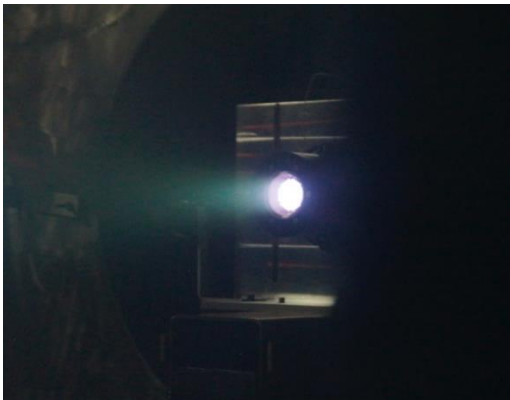


Figure 4. M-ARGO RIT3.5 based EP system firing at ESA EPL

Functional tests of the μ NRIT-3.5 were successfully performed to demonstrate repeatable thruster ignition, thrust-on mode and standby. The performance of the μ NRIT-3.5 was characterized over the operational envelope of the thruster. Electrical and flow parameters were monitored to determine thrust range, specific impulse and specific power. The test results were compared with the previously measured performances of that thruster on its classic envelope. Overall, the thruster has demonstrated performances similar to that previously measured in other test campaigns, confirming no major issues on integrated test set-

up.

One of the main objectives of the tests has been the verification of the μ NRIT-3.5 performance for M-ARGO mission. It was necessary to demonstrate thruster ability to operate at higher extraction voltages to obtain high specific impulses in the target thrust range of M-ARGO and then to demonstrate experimentally thrust to power and Isp to power trends of the thruster and their correspondence with theoretical projections.

Fig. 5 shows the results of the thrust to power consumption of the thruster for different thrust levels and variation of the thruster Isp for different thrusts achieved in the frame of the tests.

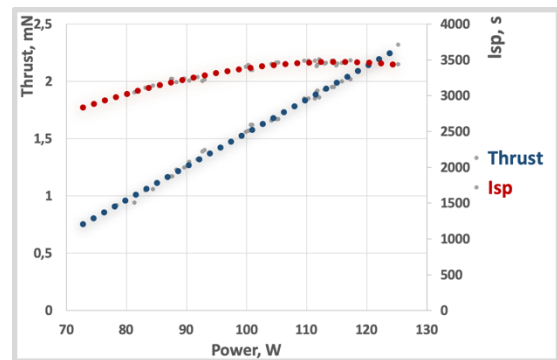


Figure 5. The power consumption of the thruster for different thrust levels between $800\mu\text{N}$ - $2200\mu\text{N}$

While the full target thrust range could be demonstrated with associated power consumption correlating good with the predicted one, achieved Isp is a few hundred seconds lower than expected although still complying with the M-ARGO requirements. However, it should be mentioned that there have been test related uncertainties associated with the flow supply lines and realistic flow consumption of the thruster might be in fact lower with correspondingly higher Isp.

Finally, an additional test has been carried out to determine capability of the same system to operate with Kr without major changes. Below are preliminary results of the RIT3.5 characterization with Kr against Xe for one of the thruster operating envelopes.

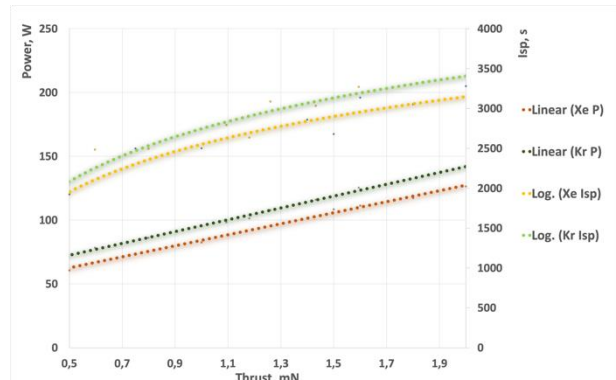


Figure 6. The power consumption and Isp of the thruster for different thrust levels for Xe and Kr, preliminary results

5. CONCLUSIONS

The HPS breadboard development has gone through the requirements and design phase and is now in the testing phase for the cold gas part, while the testing phase for the electric propulsion part of the system is completed.

The μ NRIT-3.5 based EP system verification test campaign for M-ARGO has been successfully carried out and has demonstrated system capability to deliver the required performances.

As the M-ARGO project moves further a continued effort will be required to integrate the satellite with the HPS, both with regards to requirements, but also dealing with system level concerns relating to a propulsion system on a CubeSat. Such concerns include heating power consumption, power dissipation, and physical integration between subsystems into a small formfactor CubeSat.

Solving these issues will lead to a system ready for the demanding deep space environment and contribute to a successful M-ARGO mission.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

1. Bradford, J., Williams, C. & DelPozzo, S. (2020). Nano-Microsatellite Market Forecast 10th Edition 2020, *SpaceWorks Enterprises 2020*.
2. Gonzalez del Amo, J. & Bianchi, L. (2022) <https://technology.esa.int/lab/tec-m-epl-esa-propulsion-laboratory>