µ-PPI : The smallest Hall effect thruster designed for Cubesats

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During the last decade, Marcel Guyot and his team at the *Groupe d'Étude de la Matière Condensée* ('GEMaC') laboratory at the University of Versailles – Saint-Quentin-en-Yvelines (France) have worked hard to develop the **smallest Hall Effect Thruster** ('HET') ever conceived. Building upon a technology they had developed in the early 2000s, a **full-ceramic thruster**, they succeeded in designing a thrusting unit the size of which is suitable for Cubesats. The main advantage of this new technology is that it replaces the usual coils and the ceramic shield of traditional HETs, but it keeps the main principle and advantages of this type of propulsion. Among these key advantages: **robustness, space-proven, already used by the space industry**. Marcel Guyot and his team have allowed a huge simplification of the thruster, leading to easier manufacturing processes and significantly more affordable costs.

Jean-Luc Maria and I, along with a team of several other engineers and business profiles, ambition to make a business out of this technology through the start-up Exotrail[1]. In December 2015 we sealed a first public partnership leading to funding of c.500k€ to develop a thrusting unit from the first prototype we had already built. We are now in the phase of **testing the thruster and creating the sub-systems of this unit**.

The expected performances are a thrust of 100-200µN, and the ability to de-orbit a 3-U Cubesat from an altitude of 700km in 500 days with only 35g of fuel, and fitting into at most 1U. For an altitude of 560km, which corresponds to a semi-major axis of 5960km, the expected deorbit time for a 4kg-3U Cubesat is of 142 days with the same amount of fuel. Moreover, the propulsion unit will enable the satellites to **perform new missions**: orbital rendezvous, orbital insertion, deep-space missions, station keeping, etc.

Figure 1: First ignition in Feb. 2014

This project has been an iterative process to **improve and simplify the design of a HET**. The main purpose of its development was to enable nanosatellites to reach higher orbits and still be able to de-orbit them. The use-case was a 3U Cubesat launched at an altitude of 700km, but the design was made for scalability. Indeed, our thruster as it currently exists is a scale-reduced thruster that is based on a bigger one, also made by M. Guyot among a French research initiative supported by our space national agency, research laboratories and industrial partnership (100W class, for micro-satellites).

[1] Exotrail: http://exotrail.com

Presentation of the different entities of the project

GEMaC (*Groupe d'Etude de la Matière Condensée*) is a laboratory at the University of Versailles – Saint-Quentin-en-Yvelines specialized in magnetism with a strong experience in magnetic ceramics. Furthermore, they are experts in designing void adapted devices.

The **PIT** (*Plateforme d'Intégration et de Tests*) is a space-related technology testing facility belonging to the University of Versailles – Saint-Quentin-en-Yvelines. It is the main public facility in the Paris-area for testing Cubesats and their sub-systems. However, it also performs testing for many projects led by space-related laboratories in order for their equipment to meet the highest standards. This facility will be in charge of testing each sub-system of our propulsion unit, as well as the integration on a Cubesat model. Jean-Luc Maria is the head of the PIT.

The ***École polytechnique*** is a leading French scientific institution of higher education, with the best curriculums in science, but also in economics and entrepreneurship in France. Its Student Space Center has been involved in the project for the last year and a half, as well as in other CubeSats-related projects (eg. QB50). Most of the team's business skills come from École polytechnique.

Hall effect propulsion overview

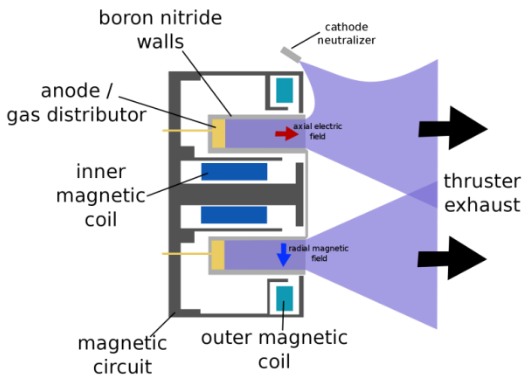

Figure 2: Schematic of the main pieces of a traditional HET

HETs have first been developed in USSR in the 60's and are now used by all major space agencies and satellites manufacturers. They are based on the acceleration of ions thanks to an electric field. This field is created between an external cathode and an inner anode. It also uses a magnetic field to keep the electrons emitted by the cathode inside the acceleration channel. This magnetic field used to be created *via* coils, which are protected from the plasma inside the channel by a ceramic wall.

Our patented innovation comes from the **replacement of the coils and the ceramic wall in the channel with a magnetic ceramic**. This innovation enables a simpler design and a lower electrical consumption. However, the main characteristics of an HET are conserved: an ISP over 1000 and a low power consumption of less than 5W for the whole unit.

Performance targets

The thruster has been designed to have the following performances:

- **Thrust**: 100 – 200µN
- **Fuel consumption**:10µg/s (Xenon)
- **Mass of the thruster**: 10g
- **Power consumption**: 3W for the cathode
- **Isp**: 1500s
- **Cathode voltage**: 300V
- **Fully magnetic ceramics design**: no need of a channel shield or power-hungry coils

And the propulsion unit has been designed to fit in a Cubesat:

- **5W** of maximum power consumption
- **Scalable size** from ½U to 1U, depending on the amount of fuel required
- Weight to be scaled with the volume of the unit, but less than the traditional 1.3kg/unit, scale-down possible if less fuel is required
- **Plug-and-play interface** with the on-board computer
- **Dedicated power conditioning and computing power** inside the propulsion unit

Our solution has been tailor-made for Cubesats and meets all the requirements linked to this standard.

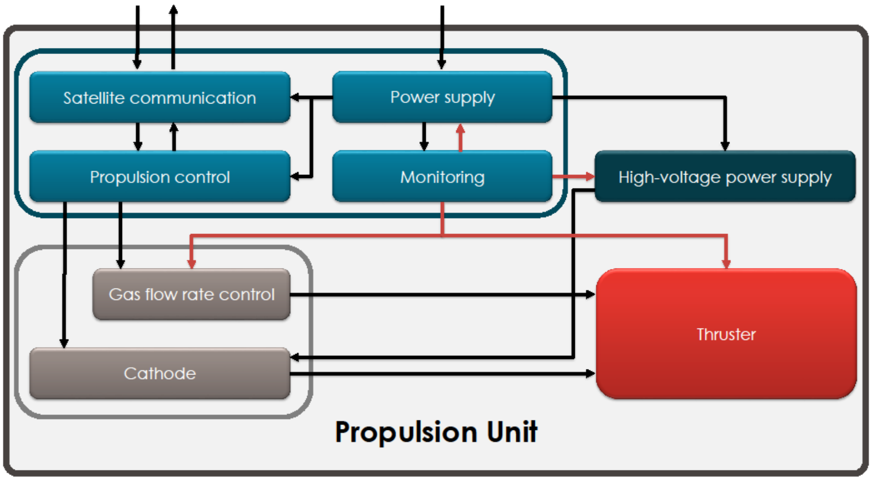

Figure 3: Links between the sub-systems of the propulsion unit

Technical Feasibility and Reliability

The proof of concept of the thruster has already been made by the GEMaC and our team is currently characterizing the thruster and building the sub-systems that will be used in the propulsion unit:

- **Power management**: low-voltage for the control of the unit and communication with the on-board computer, high-voltage for the cathode
- **Controller**: to ensure user-friendliness, the propulsion unit will have a micro-controller that will take care of communications, thrusting operations, and status monitoring
- **Fuel tank**: our team has a heritage of a tank used in EXOMARS and Mars Science Laboratory missions. This tank can handle high pressure and is already developed, and can be scaled up or down for future missions.
- **Control valve**: our team has already secured a development with a major regarding this matter. Our projected valve will accommodate flow rates of 0 – 50µg/s with a very low power consumption, and has a flight heritage on the ROSETTA spacecraft.
- **Thruster**: the thruster is a pure passive element, exempt for the cathode.

During the last 6 months our team secured sourcing that will enable us to have **many parts in our propulsion unit that have a flight heritage**. Moreover, the design of the electronics will be made to ensure the highest degree of reliability.

Market positioning

Our main goal at Exotrail is to enable nano-satellites operators to gain control over their satellites, with the easiest integration on an existing platform. To ensure that our propulsion unit will be user-friendly. We want to develop a **plug-and-play propulsion unit**. Communication will be based on the widely used I²C protocol and the power bus will be a 5V. Furthermore, we are developing a software that could be used to link the customer's attitude control system with our thruster, enabling it to **deliver the thrust where it would be the most efficient**. All the calculations will be made in the propulsion unit, which will then communicate it to the on-board controller.

We also believe that the propulsion unit should not be an extra burden on the tight budgets of nano-satellites. Therefore, our propulsion unit is designed **not to cost more than 10-15% of the total price of the satellite** it will thrust.

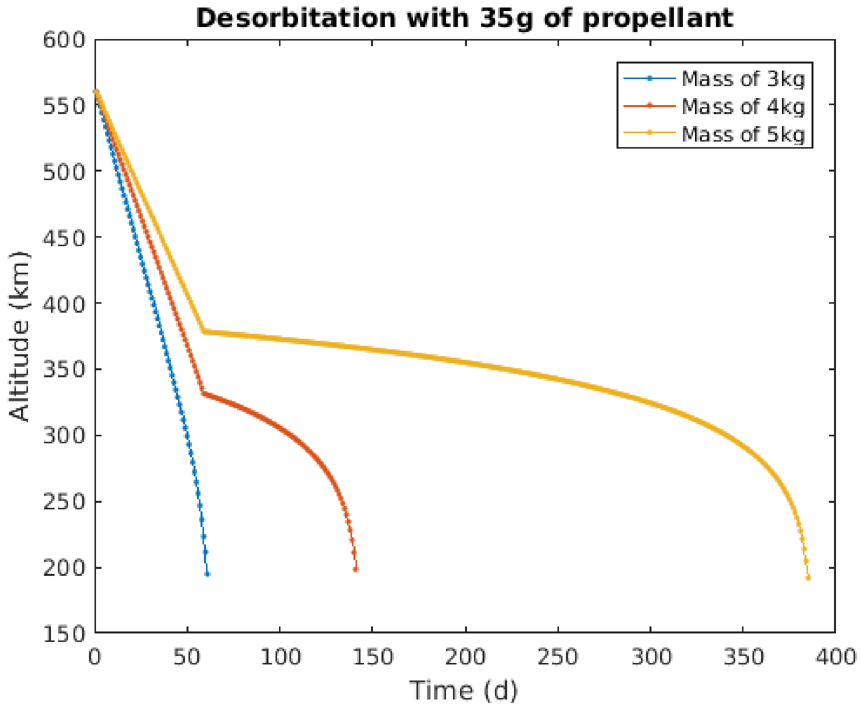

Figure 4: Simulation of the expected performances for deorbit with 35g of propellant of a Cubesat on a 6930km semi-major axis orbit

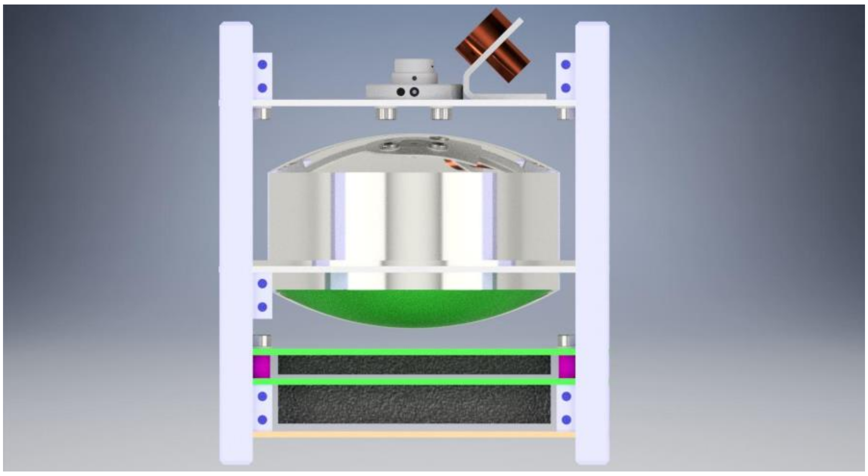

Figure 5: Model of our propulsion unit, with the thruster on the top face, capacity of the tank: 500g of xenon

Evaluation Criteria

To sum up,

1) Effectiveness

The 4kg Cubesat will be deorbited **in less than 150 days**, with only **35g of propellant**. As long as the tank can store more than that, the Cubesat will be able to perform numerous orbital manoeuvers before its deorbit.

2) Mass and envelope at launch

The envelope of the propulsion unit will be **less than 1U** and its mass **less than 1kg**. But since our current design is a **heritage of a bigger thruster**, our team is also capable of rapidly developing a bigger thruster to address the 10-100kg satellite market, but also to further reduce the size of the tank if the mission does not require a lot of fuel.

3) Cost

The cost will be limited to **10-15% of the total price** of a Cubesat.

4) Technical feasibility - Mechanical and electrical design

Our team is composed of **experimented space engineers** and the baseline for the design has already been created. Every sub-system has been identified and we have not detected any major technical issue.

5) Impact on the satellite

Our propulsion unit has been designed to fit into a Cubesat: **low power consumption**, **usual data interface**, **low thermal impact**, **½ to 1U** baseline design.

6) Reliability

Since the propulsion unit is a key factor to the success of the expected Cubesat missions, **reliability has been our top priority**. Our technology has been developed for many missions among which orbital manoeuvers and constellation deployment.

7) Safety

The propulsion unit will only be active when the on-board controller requires it to thrust. Moreover, **the pressurized fuel tank has a long flight heritage**: EXOMARS and Mars Science Laboratory missions.

8) Maintenance and testability

The unit will be tested by our team in the PIT's facilities, which therefore guarantees the **highest standards in flight certification.**

9) User friendliness

The propulsion unit will be a **plug-and-play Cubesat unit**, with a user-friendly interface to control the ADCS of the Cubesat, to ensure the **greatest efficiency during thrusting**.

10) Debris risk

Our propulsion unit has to be fed with power from the Cubesat. In case the power conditioning and distribution system of the Cubesat fails, the thruster will not be able to perform its mission. However, there is **no risk of debris creation in case of a failure of the thruster** itself, since there is no moving part in it.