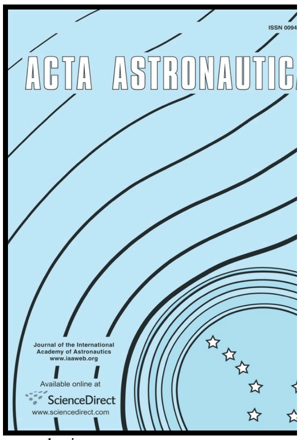

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Results of the qualification test campaign of a Pulsed Plasma Thruster for Cubesat Propulsion (PPTCUP)

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Abstract

PPTCUP (Pulsed Plasma Thruster for Cubesat Propulsion) is an ablative pulsed plasma thruster designed with the aim of providing translational and orbital control to Cubesat platforms. The qualification model presented in this paper has been developed by Mars Space Ltd, Clyde Space Ltd and the University of Southampton to produce a versatile "stand-alone" module that can be bolted on the Cubesat structure, allowing the orbital control along the X or Y-axis of the satellite. An extensive and complete test campaign to qualify the unit for space flight, which includes electromagnetic compatibility (EMC) characterization, thermal cycling and mechanical tests, has been performed according to the NASA GEVS procedures. PPTCUP is characterized by an averaged specific impulse of 655 ± 58 s and a deliverable total impulse of 48.2 ± 4.2 Ns. Finally, it has been found that the unit is compliant with the EMC requirements and can successfully withstand the thermal and mechanical loads typical of a Cubesat space mission.

I. Nomenclature

BB = Breadboard Model
C = Capacitance

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E = Energy
EM = Engineering Model
EMC = Electromagnetic Compatibility
EMI = Electromagnetic Interference
g_0 = Gravitational Acceleration
GSE = Ground Support Equipment
HV = High Voltage
I = Discharge Current
I_{bit} = Impulse Bit
I_{sp} = Specific Impulse
I_T = Total Impulse
LV = Low Voltage
m_{bit} = Mass Bit Consumption
PPT = Pulsed Plasma Thruster
QM = Qualification Model
R = Resistance
V_0 = Initial Capacitor Voltage
η_{th} = Overall Efficiency

II. Introduction

Ablative Pulsed Plasma Thrusters (PPTs) have been studied and developed since the 60s and they are the first example of electric propulsion successfully employed in space as both the Zond-2 (USSR) and LES-6 (USA) satellites used a propulsion system based on the PPT technology [1]. From then on, PPTs have been designed focusing not only on high or very high energy (up to 80 kJ) devices, but also on low-energy (< 10 J) thrusters ([2] and [3]), thanks to their high scalability in terms of geometry, power input and performance and to their relative low cost. Therefore, low-energy PPTs could be successfully used for the orbital and attitude control of pico, nano and micro satellites.

Mars Space Ltd (MSL), Clyde Space Ltd, and the University of Southampton (UoS) successfully completed a research study funded by the ESA ITI-B program producing the design of the first breadboard version of a PPT for Cubesat application called PPTCUP. The aim of the thruster was to increase the lifetime of a 3U Cubesat and consequently its economical attractiveness [4] since, at the moment, Cubesats are limited by their lack of orbit control and thus their lifetime is determined by the natural, drag-induced, de-orbiting. The capabilities of a single PPTCUP unit used to perform drag compensation on board of a Cubesat are summarized in Table 1. It has to be noticed that PPTCUP could also be used to perform small orbit changes and to maintain satellites in formations enabling Cubesats to perform complex formation flying missions.

Table 1 – PPTCUP orbit keeping capabilities.

Altitude	Cubesat Size	Natural Life	Life with PPTCUP	Life increase
250 km	1U	5.7d	17d	+200%
	2U	11d	22d	+100%
	3U	17d	28d	+66%
350 km	1U	2m 8d	5m 21d	+150%
	2U	4m 16d	8m	+75%
	3U	6m 24d	10m 8d	+50%
450 km	1U	1y 5m	3y 3m	+133%
	2U	2y 10m	4y 8m	+67%
	3U	4y 2m	6y	+44%

100 cm^2 area, C_D=2.2, NRLMSISE-00 atmosphere

The first PPTCUP model delivered a satisfactory performance but could not provide the requested lifetime. Subsequent to this study, an engineering model (PPTCUP-EM) was designed to optimize performance and achieve the required lifetime. PPTCUP-EM successfully passed a lifetime test campaign and the results showed a total impulse capability of 42.9 ± 3.9 Ns delivered in about 1,125,000 shots [5].

Starting from the PPTCUP-EM design, a PPTCUP qualification model (PPTCUP-QM) has been designed and manufactured as part of an ESA ITI-C funded activity. Since the scope of this activity is to design a potential flight-qualified product, it has been decided to produce a "stand-alone" module that can be bolted on the Cubesat structure. The module can be stacked at the top/bottom of a Cubesat or in the middle of it using a standard payload adapter. Such an approach is becoming popular among Cubesat manufacturers because it allows the production of subsystems that are isolated from the main Cubesat.

An extended qualification test campaign, including electromagnetic compatibility (EMC) characterization, thermal cycling, and mechanical tests, has been performed. In this paper the PPTCUP-QM design, the experimental apparatus and the test results are presented.

III. PPTCUP-QM system design

In this section the PPTCUP-QM system design is presented. The PPTCUP-QM module consists of three main parts: the discharge chamber, which is an ablative side-fed PPT, the conditioning electronics and the external box. The overall dimensions are 100x100x33mm^3 and the total mass, including the box, is about 270 g.

The QM configuration allows the thruster and electronic board design not to be limited by the presence of the PC/104 connector that was included in the first PPTCUP-BB model [4]. Moreover, the external box provides shielding from the radiated noise generated by the thruster and assures that no arcing can occur between the thruster and the rest of the satellite. Thanks to this design approach, the same thruster unit can be used to deliver thrust along the X or Y-axis of a Cubesat (depending on how PPTCUP is mounted on the structure), hence resulting in a more versatile product and avoiding the need for expensive and lengthy requalification programs.

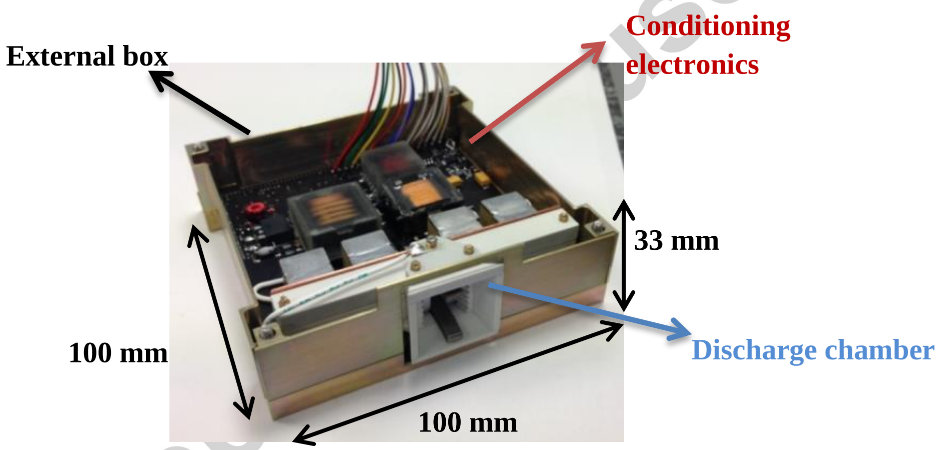

Figure 1 - PPTCUP-QM module (without the box lid to show internal details).

A. Discharge chamber design

The PPTCUP-QM is a side-fed ablative PPT. The design is very similar to the engineering model (PPTCUP-EM) that has successfully passed an endurance test [5], thus proving the reliability of a design able to reduce the carbonization phenomenon that is conventionally indicated as the main life limiting mechanism for PPTs ([6] - [9]) and one of the main issues found during the testing of PPTCUP-BB [10]. The main electrodes are made in Cu-W alloy; they are about 5 mm wide with a flared angle of 15^0. The propellant is PTFE and its initial mass is about 8 g. The whole test campaign has been performed at E = 2.00 ± 0.02 J, which corresponds to an initial voltage V_0 = 1720

± 10 V. Since the total propellant surface exposed to the main discharge is about 1e-4 m^2, PPTCUP has an energy over area ratio (E/A) of about 2 J/cm^2. The spark plug, which is used to trigger the main discharge, operates with an initial energy of about 0.01 J and an applied voltage of 7.5 kV. The PPTCUP-QM has a 1.6 µF capacitor bank, used to store the shot energy *E*. The bank consists of a parallel arrangement of 8 ceramic capacitors rated up to 2000 V and with a nominal capacitance C = 200 nF. When the capacitors are charged at 1720V, they are affected by a capacitance de-rating of about 15 %. These capacitors have been chosen after an extended test to prove their reliability when used for pulsed applications to avoid failures similar to those occurred during the PPTCUP-BB test campaign [10].

B. Conditioning electronics

The QM conditioning electronics is based on the design of the high voltage (HV) board prototype that has already proved its lifetime and reliability, being able to drive about 1,000,000 shots without failures ([5] and [11]).

The board is specifically designed to charge the main capacitor bank, to trigger the main discharge, to provide synchronization between these processes and to communicate with the rest of the Cubesat via I2C protocol. The board needs two dedicated lines: a + 3.3 V line for the digital circuit and a + 7.6 V line for the power. Finally, a 15 pins micro connector is used to electrically interface the unit with the ground support equipment (GSE), when the unit is operated in a laboratory, or with the rest of the satellite, if the unit is operated in space. As shown in Figure 2, the low voltage (LV) ground, i.e. the voltage reference of the board and the metal box, is connected to the earth ground, whereas the high voltage (HV) reference potential, i.e. the reference potential for the main electrodes and the spark plug, is left floating and insulated from the LV ground using opto-couplers.

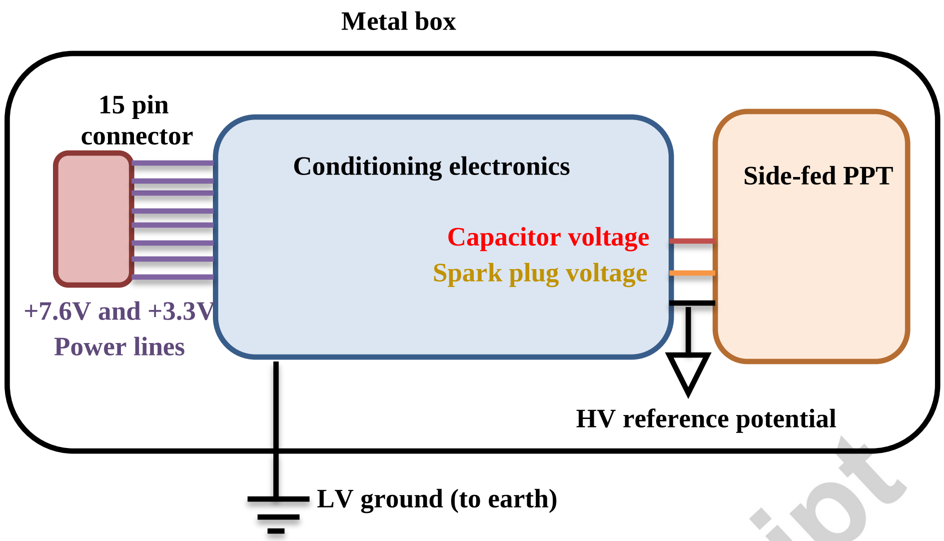

Figure 2 - PPTCUP-QM grounding scheme.

C. External box design

The aluminium external box has a thickness of 1 mm. Alocrom 1200 was chosen as final surface finish treatment to protect the box from corrosion. A dedicated structural analysis has been performed to find the lightest design that can sustain the typical loads in a space mission without permanent deformations, providing enough stiffness to the whole structure and avoiding mechanical resonance coupling. In particular the box has been designed to have its first natural frequency to be compliant with the Cubesat requirements (i.e. $f_n > 150$ Hz, as reported in [12]).

IV. Test sequence and experimental apparatus

The aim of the qualification test campaign is to fully characterize PPTCUP-QM for space flight. The test sequence consists of a thermal cycling test, vibration test and EMC characterization tests. Two performance tests are included after the thermal and the vibration tests to verify that no failures occurred during these tests (see Table 2). The unit is always be fired at its nominal initial stored energy $E = 2.00 \pm 0.02$ J and at its nominal firing frequency of 1 Hz.

Table 2 – PPTCUP-QM test sequence.

Test no	Test case
1	Thermal cycling
2	Performance test
3	Mechanical
4	Performance test

5 EMC characterization

The GSE used for the thermal cycling test was connected to the unit with cables introduced inside the chamber using a suitable thermally insulated feed-through (F/T). The chamber can be remotely programmed to provide the required temperature profile. The temperature was measured using two K-type thermocouples to verify that the device and the chamber could reach the designated temperatures throughout the test. One thermocouple was placed inside the chamber whereas the other one was placed in the center of the PPTCUP-QM box lid.

The performance tests have instead been carried out using the vacuum chamber. It is an L-shaped stainless steel chamber with the cylindrical portion 60 cm in diameter and about 1 m long. The chamber is pumped down by a Pfeiffer TPH 2200 turbo pump with an Edwards E2M80 rotary pump used as a backing pump, thus achieving a base pressure of about 7E-5 Pa and an operating pressure of about 1E-3 Pa when the thruster is fired at 1 Hz.

The discharge voltage curves were measured using a high voltage differential probe and acquired by a Tektronix oscilloscope. A torsional micro-thrust balance has been used to measure the impulse bit (I_{bit}). This balance provides reliable *Ibit* measurements in a range between 20 and 120 μNs with an error smaller than ± 8.8% [13]. The averaged I_{bit} is calculated as the mean of ten consecutive I_{bit} measurements. The mass bit consumption (m_{bit}) is measured using a Mettler Toledo high precision scale with an accuracy of ± 5 μg. The averaged m_{bit} consumption has been derived weighing the whole thruster before and after a sequence of at least 1,000 shots, then subtracting those two values and dividing by the number of performed shots. Since the typical m_{bit} values for low energy PPTs vary between 3 μg and 20 μg [1], the averaged m_{bit} can be measured with an uncertainty smaller than ± 0.5 %.

The mechanical test was performed using a LDS V8-440 shaker table. As shown in Figure 3, a three axis accelerometer was placed in the center of the PPTCUP-QM box lid and used to measure the acceleration during the test.

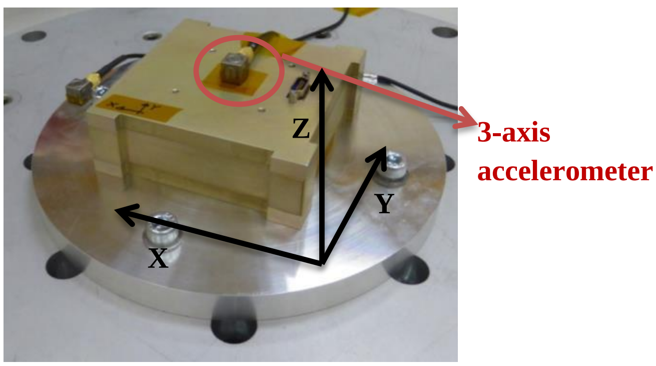

Figure 3 – Mechanical test set-up.

The EMC characterization test was performed using the bell jar shown in Figure 4 to run the test under vacuum conditions. The bell jar has one KF flange located on the central main port on the top surface. A 4-ways cross is mounted on this flange to ensure that a pressure gauge, an "up to air" valve and an electrical F/T can be used during the test. The vacuum vessel is pumped down by a Pfeiffer TPH 520M turbo pump with an MD4TC Vacuubrand membrane pump used as a backing pump, thus achieving a base pressure of about 8E-5 Pa and an operating pressure of about 2E-3 Pa when the thruster is fired at 1 Hz.

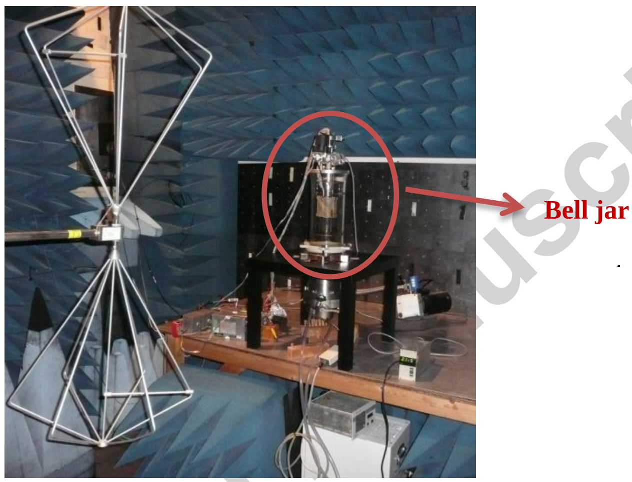

Figure 4 – EMC characterization test set-up.

V. Experimental results

A. Thermal cycling test results

The aim of this test was to demonstrate that the unit can work correctly in the range of operating temperatures, going from - 20 to + 65 °C, and survival temperatures, from -30 to + 70 °C. No requirements were set on the relative humidity. The unit underwent a 2 hour soak at hot and cold survival temperature limits before being raised to the operational temperature limits (from -20 up to 65 °C), repeating the cycle in the operative temperature range eight times. Since the test was performed in air, it was not be possible to fire the thruster with the bank of capacitors charged within the thermal chamber. However, the telemetry and the command interface have been successfully checked during the whole test as it was always possible to communicate with the board.

The box and thermal chamber temperature profiles are reported in Figure 5, whereas Figure 6 shows the voltage and the current measured on the two power lines. Unfortunately, the temperature read by the T/C installed on one of the lateral wall of the chamber and on the PPTCUP-QM box lid could not reach the operative temperature range limits because of the lack of a dwell time in the control program once the maximum or minimum programmed temperatures were reached. However, the maximum difference between the read temperature and the temperature set-points is smaller than 5%.

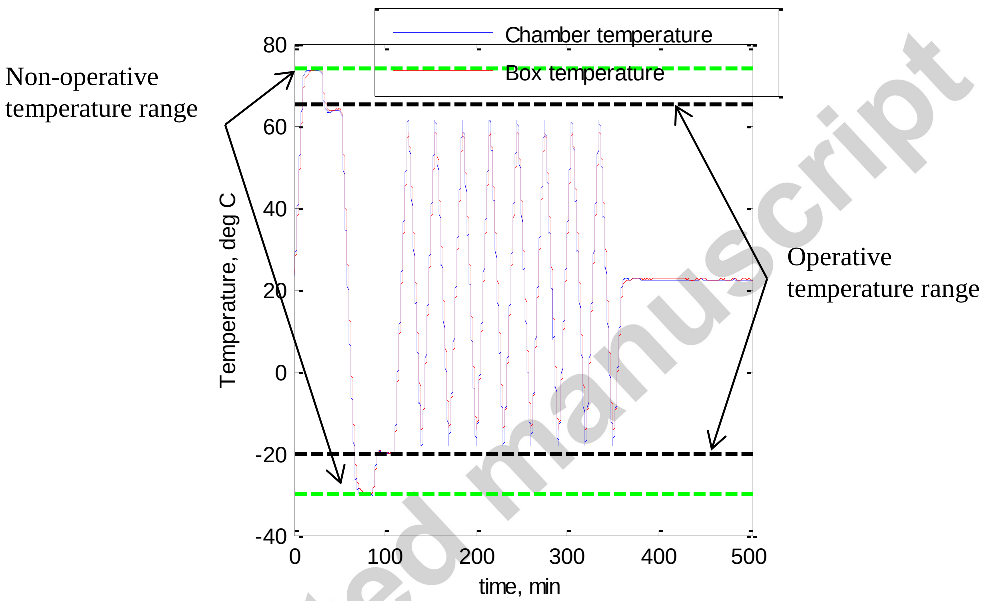

Figure 5 – Temperature profile during the thermal cycling.

The quiescent current on the +3.3 V line was about 28 mA both at the beginning and at the end of the test (i.e. at ambient temperature). There was a maximum variation of the quiescent current between extreme temperatures of 2.9 mA. The variation is due to the long harnessing and connections between the power supplies outside the chamber and the unit and it corresponds to a resistive component as the maximum current consumption was found at the lowest temperature. Finally, it has to be noticed that no current flowed on the +7.6V line because the thruster was not fired.

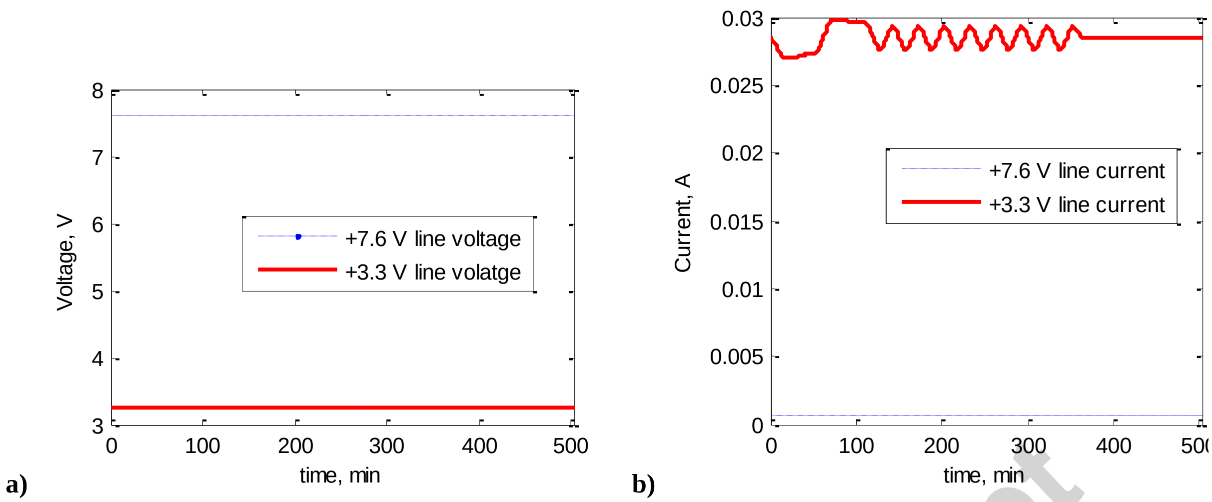

Figure 6 – a) Voltage and b) current curves during the thermal cycling.

B. Mechanical test

High sine burst and random vibration tests were performed along each main axis defined in Figure 3 respectively to apply a quasi-static load to the thruster as a simulated strength test and to demonstrate that the unit can survive the vibrations at launch. Before and after the sine burst and after the random vibration, a low sine sweep test was carried out to assess the natural frequency of the unit (f_n).

The high sine burst was performed from 5 to 50 Hz at 4g, whereas the low sine sweep test from 5 to 2000 Hz at 0.5g. The random vibration profile was in line with NASA-GSFC and is summarized in Table 3 and applied for 60 seconds.

From visual inspections performed after the end of each mechanical test cases, no damage or failures were observed during the vibration testing. The natural frequencies acquired during the sine sweep checks are summarized in Table 4. It has to be noticed that all the measured frequencies are compliant with the requirements, i.e. f_n> 150 Hz. and no significant changes in the f_n values were detected. The only exception is the f_n measured along the Z-axis after the first random vibration test. This value changed by about 22% when compared to the one measured before the same test (i.e. from 578 Hz to 453 Hz). Considering that this only happened once for the Z axis, and that no change in frequency was measured from that point onwards, it can be concluded that the reason behind it was likely to be small adjustments of the lateral walls of the external box that occurred during the first performed random vibration test.

Table 3 – Random vibration test parameters.

Frequency, Hz	Power spectral density, g^2/Hz
20	0.026
20-50	+ 6 dB/oct
50-800	0.16
800-2000	- 6 dB/oct
2000	0.026

Table 4 – Low sine sweep test results.

Axis	Test case	Main natural frequency f_n, Hz
X	Before high sine	584
	After high sine and before random vibration	578
	After random vibration	453
Y	Before high sine	1137
	After high sine and before random vibration	1135
	After random vibration	1135
Z	Before high sine	679
	After high sine and before random vibration	676
	After random vibration	660

C. Performance test

In this section the results of the performance tests are reported. The specific impulse (I_{sp}) and the overall efficiency (η_{th}) can be calculated using equations 1 and 2 once I_{bit} and m_{bit} have been measured:

$$I_{sp} = \frac{I_{bit}}{m_{bit} g_0} \qquad (1)$$

$$\eta_{th} = \frac{Ibit^2}{2 \cdot m_{bit} \cdot E} \qquad (2)$$

where g_0 is the standard gravitational acceleration at sea level g_0 = 9.81 m/s^2. Since I_{bit}, m_{bit} and E are independently measured, the relative errors of I_{sp} and η_{th} can be calculated with the following equations [15]:

$$\frac{\delta I_{sp}}{I_{sp}} = \sqrt{\left(\frac{\delta I_{bit}}{I_{bit}}\right)^2 + \left(\frac{\delta m_{bit}}{m_{bit}}\right)^2} \qquad (3)$$

$$\frac{\delta \eta_{th}}{\eta_{th}} = \sqrt{2 \cdot \left(\frac{\delta I_{bit}}{I_{bit}}\right)^2 + \left(\frac{\delta m_{bit}}{m_{bit}}\right)^2 + \left(\frac{\delta E}{E}\right)^2} \qquad (4)$$

A comparison of the discharge voltage curves acquired after the thermal and after the structural tests is reported in Figure 7. The curves, obtained averaging the data of ten different shots in each test case, are very similar and show that the main discharge voltage goes to zero in about 2 μs, a time similar to that found during the PPTCUP-EM test campaign [5]. The voltage measurements were also noticed to be very repeatable with a standard deviation of the first negative voltage peak of about 0.87 % for the post-thermal and 1.01 % post-vibration tests respectively.

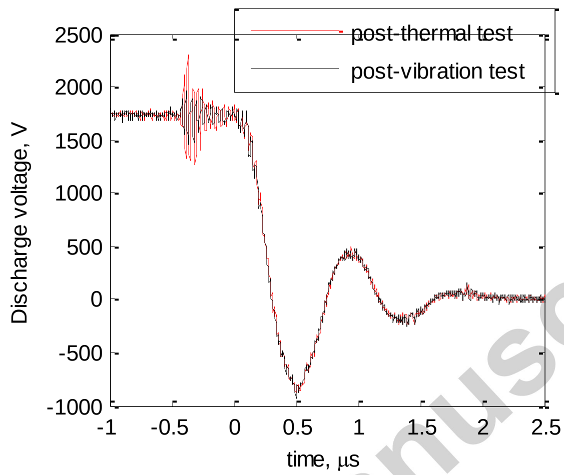

Figure 7 – Comparison of the typical discharge voltage curve acquired after the thermal cycling and the mechanical tests.

The PPTCUP-QM performance is summarized in Table 5, together with the results obtained during the PPTCUP-EM test campaign. It has to be noticed that the PPTCUP-QM performance, in terms of I_{bit}, I_{sp} and η_{th}, is in very good agreement with the PPTCUP-EM performance, even down to the uncertainties, small and consistent. This confirms that the unit can withstand the thermal and mechanical loads of a space mission.

Table 5 – Performance test results summary.

Parameter	Post thermal test	Post mechanical test	PPTCUP-EM [5]
I_{bit} (μNs)	39.2 ± 3.5	40.0 ± 3.5	38.2 ± 3.4
m_{bit} (μg)	6.5 ± 0.1	5.9 ± 0.1	6.4 ± 0.1
I_{sp} (s)	613 ± 54	696 ± 62	608 ± 55
η_{th} (%)	5.9 ± 0.7	6.8 ± 0.9	5.7 ± 0.7

D. EMC characterization test

This test was aimed at the characterization of the electromagnetic noise produced by the system. The EMC characterization was performed according to the NASA MIL-STD-461C and 462 standards [14] as already done in the past for other PPTs [16], [17], [18].

The tests covered:

- the conducted emissions on the power leads in the range between 100 Hz to 50 MHz (both in differential and in common mode);
- the radiated electric field in the range between 150 kHz and 1.8 GHz;
- the radiated magnetic field in the range between 20 Hz and 50 kHz;
- the radiated susceptibility due to radiated electric field in the range between 14 kHz and 1 GHz.

Since it is necessary to keep the bell jar pumping system (including the power supplies and the pump cooling system) on during the entire test, it has been decided to repeat each test case twice. In the first run, no shots were commanded and only the background noise (i.e. the noise generated by the pumping system and the power supplies) was detected. In the second run, the thruster was fired at the nominal frequency of 1 Hz and the data acquired.

In previous publications regarding PPT qualification programmes, it is has been pointed out that the MIL standards used by NASA GSFC 7000 [14] are unsuitable to characterize an inherently pulsed device, having been developed for devices that work continuously. For this reason, to better judge the EMC gathered results and to assess the suitability of PPTCUP to be used on-board of a spacecraft, the results will be compared to those acquired during the flight qualification of the PPT developed for the NASA Earth Observing 1 mission (from now on referred to as EO-1 PPT) [16], [17]. It has to be noted that the EO-1 PPT was successfully used in flight and that according to what reported in [19], the EO-1 PPT electromagnetic emissions did not affect the other spacecraft subsystems and did not have any harmful effect on the payloads.

1. Conducted emission test results

The conducted emission tests have been performed using suitable Rogowski coils to measure the AC current flowing in the cables that feed the PPTCUP-QM in the range between 100 Hz to 50 MHz.

A total of five acquisitions have been performed: three for the differential mode, i.e. +3.3 V, + 7.6 V and ground, and two for the common mode, i.e. + 3.3 V and ground cables and +7.6 V and ground cables.

The results of the test performed in the differential mode on the ground line are shown in Figure 8, where the blues curves represent the background noise acquired without firing the thruster and the red curves represent the noise detected firing the PPT. The level of noise measured during the testing was often smaller than the requirements and it was not always possible to distinguish the PPT noise from the background noise. However, peaks exceeding the requirements have been found during the acquisitions. These peaks are mainly centred around 30 kHz and in the range between 2.5 and 15 MHz and exceed the requirements by a maximum of about 45 dB. Nevertheless, looking at the comparison reported in Table 6 between the PPTCUP data (Figure 8) and the EO-1 PPT data [17] (Figure 9), it is possible to notice that the magnitudes of the detected noise are similar.

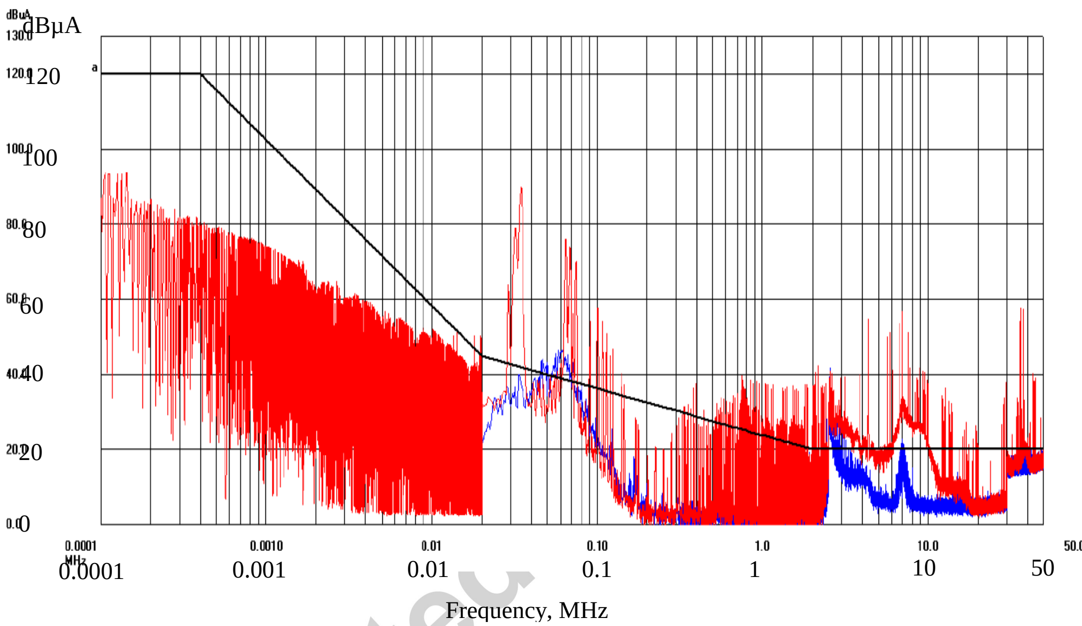

Figure 8 – Conducted emissions (ground line, differential mode) test results. The blue and red curves represent respectively the background noise and the noise with the thruster on. The black line indicates the requirements (from [14]).

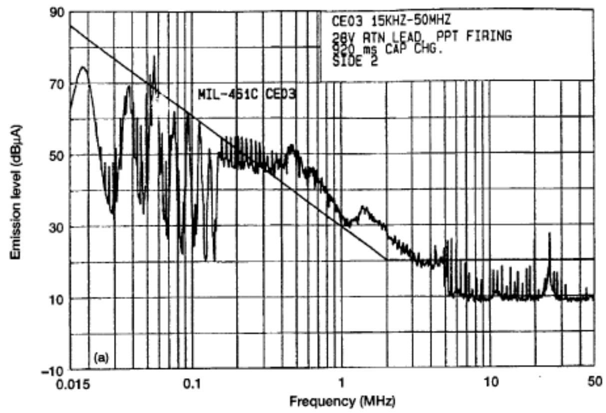

Figure 9 – EO-1 PPT conducted emissions [17].

Table 6 - Conducted noise comparison between PPTCUP-QM and EO-1 [17]

	PPTCUP-QM			EO1PPT		
Freq. range, MHz	min, dB	mean dB	max dB	min, dB	mean dB	max dB
0.01-0.1	5	30	90	20	50	80
0.1-1	0	20	60	20	45	60
1-10	0	20	55	10	20	35
10 -50	5	15	50	10	15	30

2. Radiated emission test results

The radiated emissions test have been performed using four different antennas to measure the radiated noise generated by the PPTCUP-QM module, covering the range between 150 kHz to 1.8 GHz for the radiated electric field and the range between 10 Hz to 50 kHz for the radiated magnetic field. The antennas were placed at approximately 1 m from the thruster. The results of the radiated electric and magnetic fields are shown in Figure 10 and Figure 11 respectively. The level of noise measured during the testing, i.e. the red curves in the figures, was often impossible to distinguish from the background noise, i.e. the blue curves.

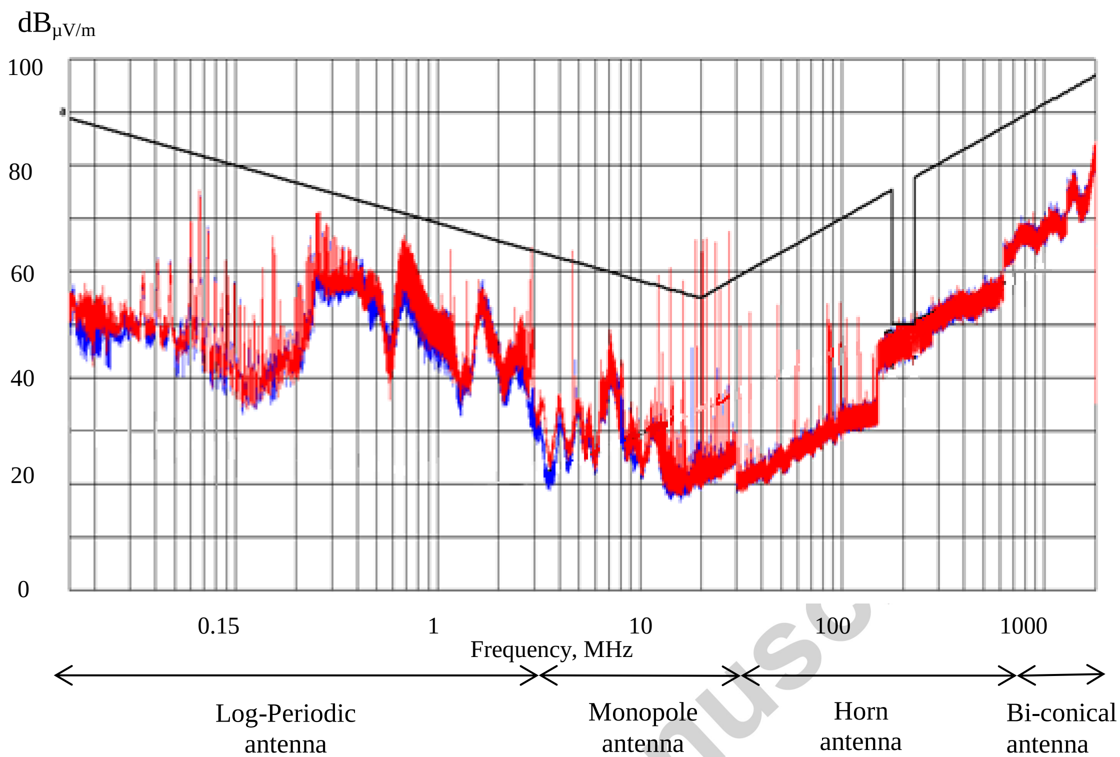

Figure 10 – Radiated electric field test results. The blue and red curves represent respectively the background noise and the noise with the thruster on. The black line indicates the requirements (from [14]).

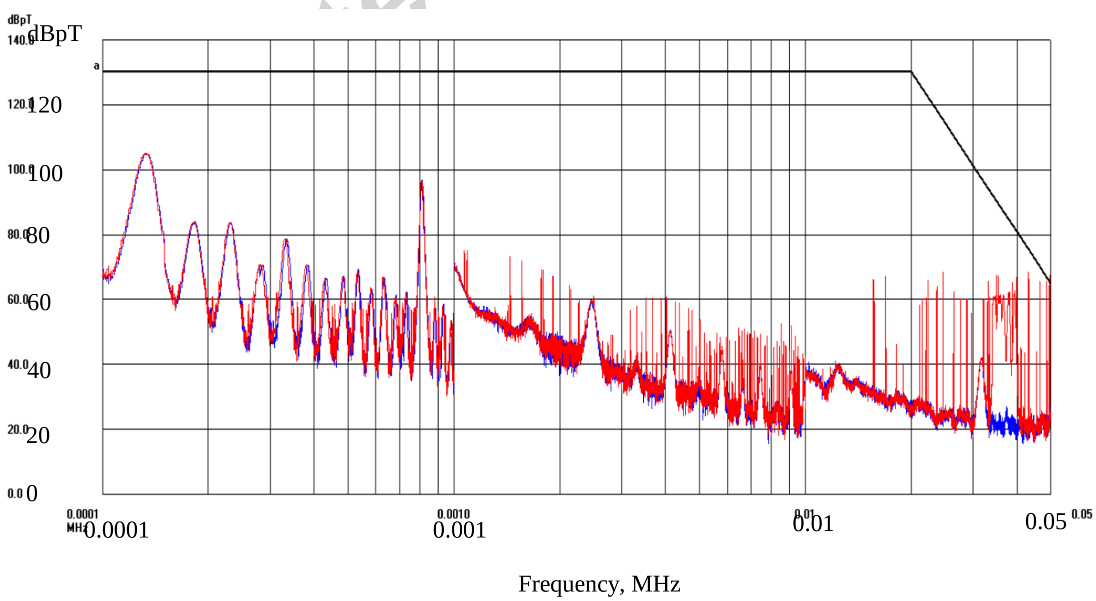

Figure 11 – Radiated magnetic field test results. The blue and red curves represent respectively the background noise and the noise with the thruster on. The black line indicates the requirements.

The radiated magnetic field is compliant with the requirements in the whole range of frequencies. For what concerns the electric field, it has been found that the noise generated by the unit is very similar to the background noise. When the thruster was fired, several spikes were detected in the range between 100 and 500 MHz. These are likely to be generated by the spark plug discharge that is characterised by a fundamental frequency of the order of hundreds of MHz [5].The spark plug was already found to be the most likely main source of the noise during the preliminary noise characterisation of the PPTCUP-EM [5]; this confirmed what was theorized for the first time during the development of the LES-6 and LES-7/8 PPTs between 1960s and early 1970s [20], [21].

It is instructive to compare the radiated E-field noise measurement with the EO-1 PPT data [16] reported in Figure 12. The comparison between these data reported in Table 7 shows that the PPTCUP noise levels are always lower than those of the EO-1 PPT, hence providing confidence that the PPTCUP noise level will be acceptable to the rest of the spacecraft subsystems.

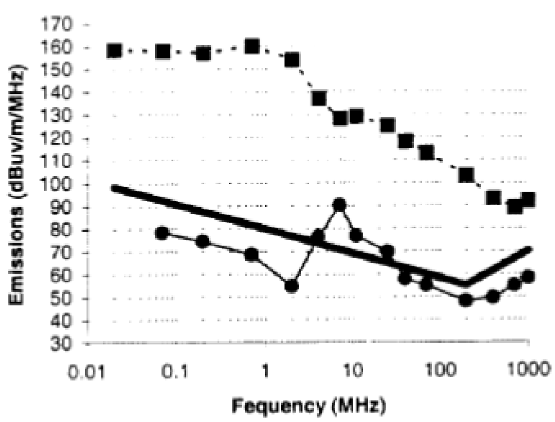

Figure 12 – EO-1 PPT radiated electric field test results [16]. The solid line is the limit set for the unit, the circle and square markers indicate the results obtained respectively with and without the additional shielding envelope.

These data confirmed that the use of an external box to enclose the PPT and its conditioning electronics is recommended to limit the radiated noise. However, it has to be noticed that the introduction of the EMI shield increases the total PPTCUP dry mass by about 28%.

Table 7 - Emitted E-field noise comparison between PPTCUP-QM and EO-1 PPT [16].

	PPTCUP-QM			EO1PPT		
Freq. range, MHz	min, dB	mean dB	max dB	min, dB	mean dB	max dB
0.1-1	40	45	75	60	68	75
1-10	40	55	70	55	75	90
10-100	20	35	60	50	63	75
100-1000	20	25	65	50	55	60

3. Radiated susceptibility test results

The radiated susceptibility test was carried out over a frequency range of 14 kHz to 1 GHz. The applied susceptibility electric field level was 2 V/m as described in the NASA EMC standards. The emitters were placed at approximately 1 m from the thruster. The test was successfully passed with PPTCUP-QM operating without failures during the test. Moreover, no changes to the module functionality were found in post-test operations.

VI. Conclusions and future work

A pulsed plasma thruster for Cubesat application (PPTCUP-QM) is undergoing an extended qualification test campaign and it has successfully completed the thermal cycling, vibrations and EMC characterization tests. The performance of the thruster has been checked after the thermal and the mechanical tests to verify that no damage occurred in the unit during these tests.

Results from the test campaign performed up to the paper submission date show that PPTCUP-QM works correctly in the operating temperatures range (i.e. from -20 to +65°C), withstands the mechanical vibrations during launch and has the main natural frequencies compliant with the requirements. The results of the EMC characterization test show that the electromagnetic noise generated during the main PPT discharge is mostly compliant with the requirements or small enough not to be distinguishable from the facility background noise. Moreover, the level of noise emitted by PPTCUP-QM was found to be smaller than or comparable to the noise measured during the EMC testing of the EO-1 PPT that has been successfully launched and used in space without creating issues to the other spacecraft subsystems [16], [17]. Finally, it has been found that the performance of the thruster is very similar to the one measured during the PPTCUP-EM test campaign [5], since the unit is characterized by an averaged I_{sp} = 655 ± 58 s and a deliverable total impulse I_T = 48.2 ± 4.2 Ns. This is again in line with the performance requirements, i.e. I_T of at least 44 Ns.

In the next months, PPTCUP-QM will complete the lifetime test to further confirm the reliability of the thruster and to quantify the actual total impulse that the unit will deliver. Moreover, future work will focus on developing a predictive PPT numerical model to be used to optimise the thruster design and maximise its performance. This work will be carried out thanks to funding from the UK Technology Strategy Board.

VII. References

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Highlights:

We have designed and manufactured a PPT for Cubesat applications.

We are running an extensive test campaign to qualify the system for space flight.

Mechanical, thermal cycling and EMC tests have been successfully completed.

The device will be the first fully qualified PPT for Cubesat applications.