UPMSat-2 Micro-satellite: In-orbit Technological Demonstration for Education and Science.

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ABSTRACT

The UPMSat-2 micro-satellite was launched on September the 3rd 2020 at 01:51:10 UTC from Kourou spaceport in French Guyana. The VV16 Vega Flight has been the first low Earth orbit rideshare commercial flight with a total of 53 satellites (7 of them micro-satellites) to be released by the launch vehicle, arranged in the modular SSMS (Small Spacecraft Mission Service) dispenser. UPMSat-2 is an educational, scientific and in-orbit technological demonstration microsatellite project led by the IDR/UPM research institute from Universidad Politécnica de Madrid (UPM), Spain. This mission can be considered as a logical extension of the IDR/UPM Institute activities focused on designing small satellites to be used as educational platforms of first level. Thereby, UPMSat-2 (as well as its precursor, the UPMSat-1) has the main objective to give students the competences for designing, analyzing, manufacturing, integrating, testing and operating the platform. UPMSat-2 also includes a set of scientific payloads and equipment to be tested in space, provided by research institutions and private companies. The UPMSat-2 is a 50 kg-class microsatellite developed for a 2-year LEO mission with a geometrical envelope of 0.5 x 0.5 x 0.6 m. Since launch, the satellite is orbiting the Earth in a sun-synchronous orbit of 500 km of altitude, passing over the IDR/UPM ground station four times a day. The satellite operation is being carried out by students and professors of the Master in Space Systems (MUSE), an official Master's program of UPM organized by IDR/UPM. This work describes the most relevant characteristics of UPMSat-2, its payloads, technological contributions, and the main activities performed up to the launch, including participation in the launch campaign in French Guyana. The lessons learned during the mission are also summarized. Finally, the importance and benefits of incorporating actual space systems design and development within academic programs is also emphasized, as it improves these programs with constant and direct feedback.

INTRODUCTION

The UPMSat-2 is a 50 kg-class microsatellite designed, manufactured and operated by the research institute 'Ignacio Da Riva' (IDR/UPM) from Universidad Politécnica de Madrid. UPMSat-2 is a long-term project that started in 2011 as a logical continuation of the UPMSat-1, the first microsatellite manufactured, launched and operated in space by IDR/UPM.

The microsatellite projects developed within IDR/UPM are framed within the Master`s Degree in Space Systems (*Máster Universitario en Sistemas Espaciales*, MUSE)[1,2], an official Master's program organized by IDR/UPM.

Those platforms are projected with a double objective. Firstly, microsatellite platforms are used as an educational tool to involve engineering students in real projects of the aerospace sector, as a part of the Project Based Learning (PBL) philosophy of MUSE. The benefits of PBL methodology are widely known and the implementation of projects as UPMSat-2 in an academic environment has proven to be an extremely useful tool to allow students to train their skills in demanding working environments and boots the engineering student's motivation and learning capacity.

Secondly, the UPMSat-2 is conceived as an in-orbit technological demonstration platform, designed to evaluate the behavior of systems and equipment in the extreme conditions that occur in space.

Those types of platforms enable data collection of great value for space systems manufacturing companies and, in addition, allow the equipment qualification for latter use in space conditions. Indeed, UPMSat-2 represents the framework of a successful collaboration between university and several Spanish and international companies of the space sector.

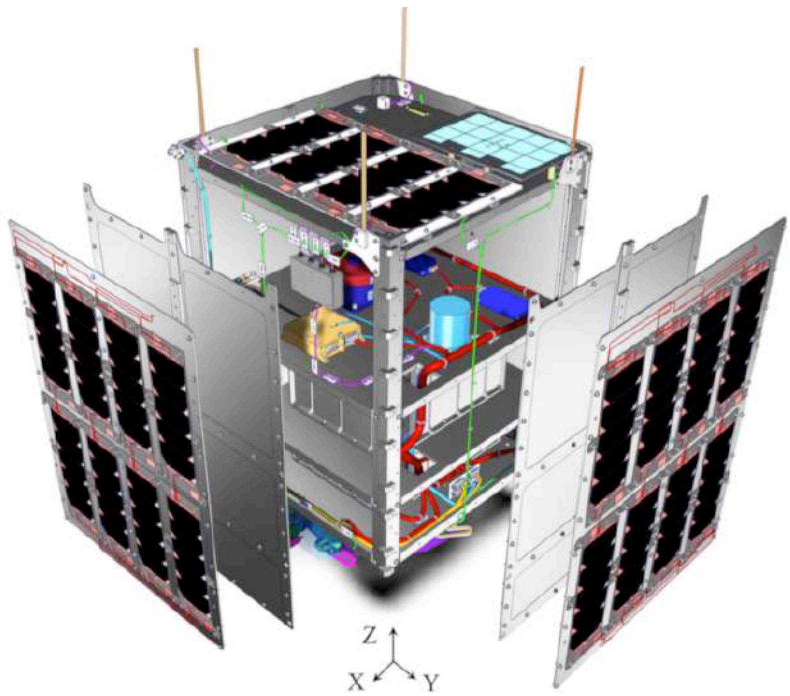

Figure 1: UPMSat-2 microsatellite flight model CAD detail.

The UPMSat-2 microsatellite platform is a flexible and modular platform with a geometrical envelope of 0.5 x 0.5 x 0.6 m^3.

Due to its characteristics and morphology, UPMSat-2 structure allows a distribution of subsystems and equipment similar to that of conventional satellites but much more versatile in terms of mass and cost. In addition, the UPMSat-2 configuration based on trays, constitutes a flexible platform that allows the accommodation of multiple instruments and payloads. Indeed, this characteristic enables its future adaptation of different missions and objectives.

UPMSat-2 describes a Sun-Synchronous orbit of 500 km of altitude, 97 deg of inclination and local time of the ascending node (LTAN) of 10:30 a.m. UPMSat-2 completes 15 orbits around the Earth every day, passing twice over the IDR/UPM Ground Station.

An outline of the satellite and the mission is presented in Table 1 and a picture of UPMSat-2 is shown in Figure 1.

Table 1: Outline of the UPMSat-2 mission

Mission Life	2 years
Mass	50 kg
Dimensions	0.5 x 0.5 x 0.6 m^3
Attitude Control system	Purely magnetic: • SSBV magnetometers (1 nominal, 1 spare) • ZARM Technik AG magnetorquers (3 axis actuation) • Magnetic control law designed by IDR/UPM
Thermal Control	Passive for the microsatellite, active for battery thermal stability
Power	Power subsystem based on solar photovoltaic panels and a battery: • 5 body-mounted solar panels of Azur Space 3G28C triple junction solar cells. • Li-Ion battery of 18 Ah designed by SAFT • Direct Energy Transfer (DET)
On-board Electronic Box (EBOX)	Based on FPGA (designed by IDR/UPM and TECNOBIT (Oesia group) and programmed by STRAST/UPM*). The E-BOX includes the on-board computer; data handling; power supply control; and power supply distribution.
Communications	• Uplink and downlink at 437 MHz (additional downlink at 400 MHz). • 4 monopoles antennae system for omnidirectional radiation pattern. • Ground station located in UPM Montegancedo campus

* http://www.dit.upm.es/~str/

The UPMSat-2 project has involved a major effort for professors, research and administration staff of the groups involved in their development: IDR/UPM Institute and STRAST group. The latter is the responsible for the on-board and ground station software development.

The project development has improved and promoted the collaboration of the university with several companies and organizations that have participated directly or indirectly in the satellite development (AIRBUS D.S., INTA, among others) and provided support throughout the life cycle of the project.

Along with its main objectives as technological demonstrator and teaching tool, UPMSat-2 has meant the confirmation of UPM capacity to develop, manufacture, integrate, test and operate a space platform with modern features, retaining in the project execution all the complexity of a complete space mission but developing the activities in an academic environment. All the processes, methods and standards used for the UPMSat-2 development are in accordance with the European aerospace sector.

Additionally, the window opportunity that the development of the UPMSat-2 has represented for an academic program such as MUSE needs to be also emphasized. The first edition of MUSE was the academic year 2014/2015 and, as the education in this master's program is based in Project Based Learning (PBL), the students were encouraged to work in problems related to the UPMSat-2 since the first semester.

For instance, initial testing campaign of the different payloads (P/L) and subsystems were carried out mostly by students from MUSE. Besides, this satellite has had a quite large impact on subjects like *Space Integration and Testing* or *Power Subsystems*.

In the case of *Space Integration and Testing*, this subject is organized around the planning and execution of a full AIT campaign of a space system (equipment, subsystem or full satellite platform). UPMSat-2 provided a golden opportunity to use a full space platform to teach students about the discipline and to use real projects for the practices of the subject. Therefore, some of the equipment testing and Assembly and Integration procedures of the UPMSat-2 were derived from the work of MUSE students.

In particular, MUSE students, guided by the professors and the research staff in charge of IDR/UPM testing facilities, developed the qualification testing campaign of the Electronic Box (E-BOX) of the UPMSat-2: mechanical and thermal vacuum testing.

With regard to the second subject, *Power Subsystems*, the architecture of the UPMSat-2 power distribution system (see Figure 2) has been selected as the case study to analyze a satellite. The solar panels, the battery, and the DC/DC converters of the case study proposed to the students are analyzed with real testing data from the UPMSat-2 development process. A mission is also proposed within the case study, the consumption of the payloads and the satellite systems (OBC, magnetometers and magnetorquers) being also extracted from the UPMSat-2 mission.

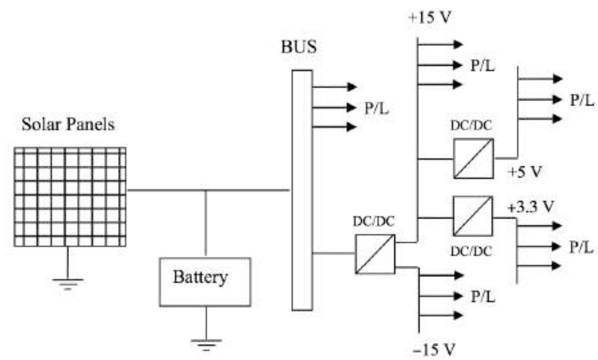

Figure 2: Simplified sketch model of the UPMSat-2 power distribution system.

Finally, students performed practical exercises on satellite harness design, the UPMSat-2 geometry being selected as the one to correctly connect the harnesses manufactured by the students (see Figure 3).

Figure 3: MUSE students during the harness development exercise within the subject *Power Subsystem*.

UPMSAT-2 SUBSYSTEMS AND PAYLOADS

As a technological demonstration platform, the UPMSat-2 includes a set of instruments and experiments to be tested in space:

- *Micro Thermal Switch* developed by Iberespacio: It is a miniaturized thermal control device that works as a thermal switch controlling the activation or deactivation of space instrumentation depending on its temperature.

- *Electronic Box* (E-BOX): The E-BOX unit constitutes the on-board electronics including the on-board computer, the power supply and distribution boards, the data acquisition and control. It is developed by TECNOBIT S.L. (Oesia group) under the specifications defined by the IDR/UPM institute and STRAST group. The E-BOX unit also includes the communications board.

- *Bartington Magnetometer* developed by Bartington Instruments Ltd.: It is a high-performance sensor for measurement of the Earth's magnetic field.

- *Reaction Wheel* developed by SSBV Space & Ground Systems: It is a miniaturized inertia wheel to modify the satellite's attitude and to allow pointing in one direction in space.

- *Experiment SS6* developed by IDR/UPM: It is a system composed of two sets of three sensors. Its objective is to include information about the position of the satellite with respect to the Sun in the control laws of the Attitude Control Subsystem.

- *MRAD* experiment proposed by TECNOBIT S.L. and STRAST group: This experiment aims to evaluate the effect on radiation in on-board space equipment.

- Purely magnetic attitude control law, developed by IDR/UPM: The nominal attitude control subsystem of the UPMSat-2 includes two magnetometers and three magnetorquers. Therefore, it only uses magnetic sensors and actuators. The control law is a variation of the B-dot control law developed in the IDR/UPM institute[3] that allows setting the angular velocity of the satellite and orients the axis of rotation perpendicular to the orbit. This makes the UPMSat-2 one of the first purely magnetic spinning satellites capable of controlling its angular velocity.

An interior picture of the UPMSat-2 taken during the Assembly, Integration and Testing campaign is presented in Figure 4. The interior trays system of the microsatellite platform can be configurable depending on the payload required volume. For the UPMSat-2 mission, only the upper volume is dedicated to the payloads.

UPMSat-2 includes all the subsystems needed to ensure mission success and they also constitute technical and scientific developments of the professors and research staff of IDR/UPM.

As is summarized in Table 1, the power subsystem is composed of a Li-Ion SAFT battery of 18 Ah and five fixed solar panels, located on the lateral faces of the cuboid and on its upper face.

Figure 4: Interior picture of the UPMSat-2 during the AIT campaign in the IDR/UPM ISO 8 clean room.

The UPMSat-2 solar panels are built up with SPVS5S solar modules, manufactured by Selex Galileo, and composed of triple junction solar cells (AZUR SPACE 3G28C, efficiency class 28%). The cells are mounted on an Al substrate instead of the traditional one composed of composite CFRP + Al substrate. The selected substrate is made of black anodized aluminum in order to guarantee complete insulation towards the electrical network. Each module is composed of 5 solar cells and it is autonomous in terms of the supporting structure and connection terminals.

The lateral solar panels are formed by four parallel-connected groups of two series-connected SPVS-5S modules, while the solar panel located in the upper satellite face is made up of two parallel-connected groups of two series-connected modules. The solar cells modules are directly fixed on the lateral support panels of the satellite, which are fabricated in aluminum EN AW-7075 and coated with Alodine® 1200 to minimize corrosion. Areas without surface treatment are also covered with 1 Mil Kapton® Tape and a blocking diode is included in each of the solar cells' series, with a forward voltage of 0.8 V.

The final configuration of the solar panels can be shown in Figure 5 and the *I-V* and *P-V* curves from a lateral panel are presented in Figure 6. The curves are obtained from both, the simulations of a 1-diode/2-resistor model and an illumination testing[4].

Figure 5: UPMSat-2 lateral solar panels detail. Picture taken during the mechanical test campaign within the IDR/UPM institute facilities.

The Attitude Control Subsystem is purely magnetic, using in its nominal operation three magnetorquers (located along the three axes of the space) and two magnetometers.

This set of actuators and sensors allows keeping the rotation axis (Z-axis) perpendicular to the orbital plane and with a speed of rotation around it approximately constant and equal to 0.1 rad/s.

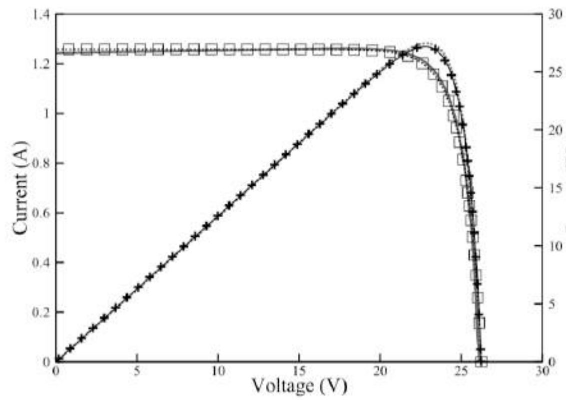

Figure 6: Comparison between measurements and simulations of the *I-V* and *P-V* curves of a UPMSat-2 lateral panel. (--□--) *I-V* and (−+−) *P-V* curves measured during an illumination test of the solar panels; (−−−) *I-V* and (- - -) *P-V* curves simulated with a 1-diode/2-resistor model[2]

In order to maintain the satellite's orientation, a new control law based on a modification of the B-dot control law was designed and implemented[3,5]. The control algorithm is based on the measurement of the magnetic field and its derivative. Therefore, the magnetic moment the magnetorquers must provide is calculated at each step of the control. The only element needed to calculate the control torque is the magnetic field in the satellite's body axes. As the determination of the orientation is not required, the control algorithm is greatly simplified and the data processing needs are reduced.

The UPMSat-2 Thermal Control Subsystem has been developed and validated with the IDR/UPM Institute's own numerical models and simulations. It is primarily passive, using single layer or multilayer insulation (SLIs or MLIs) blankets, materials with low thermal conductivity of specific surfaces finishes in the appropriate locations. In addition, a set of temperature sensors measures the temperature of critical and representative elements all over the satellite.

In addition, the satellite's battery includes its own active thermal control system using a set of heaters whose activation/deactivation thought thermostats depends on the temperature, as shows Figure 7. The goal is to keep the UPMSat-2 battery within its operative temperature margins.

Figure 7: Thermal control harness of the UPMSat-2 Li-Ion battery.

The on-board communication subsystem is composed of the communication board and the antennae system. The latter is formed by four monopoles arranged in right-handed circular polarization (RHCP), composing a quasi-omnidirectional radiation pattern. The losses and total gain of the antennae system were evaluated through radiation pattern simulations and later compared with experimental measurements obtained in a ground-reflection antenna range testing campaign performed in INTA (Instituto Nacional de Técnica Aeroespacial) facilities. Radiation pattern for the antennae system is shown in Figure 8, for a cut along the satellite equator.

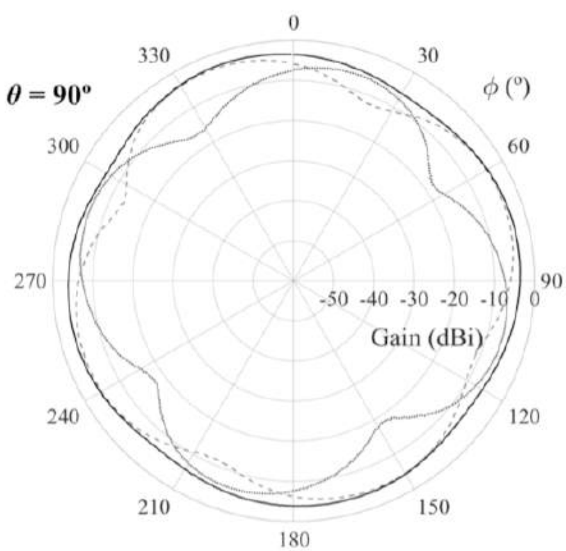

Figure 8: UPMSat-2 antennae system radiation pattern (measured at INTA facilities). (- -) RHC polarization; (…) LHC polarization; and (---) total gain.

To maintain a constant communication and maximize uplink and downlink gain, the IDR/UPM Ground Station has a polarization commutation system that allows commuting ground antennas between LHCP and RHCP.

The communication board operates through a half-duplex communication protocol, transmitting in the 400 MHz band (scientific RF band) and 437 MHz (amateur RF band). Transmission speeds are between 1200 and 9600 baud depending on the modulation scheme.

The onboard software consists of a number of subsystems that controls the operation of the satellite: the ADCS, the platform monitoring, the Telemetry/Telecommand (TMTC) and the storage subsystems, with first three having the highest criticality (level B, as per ECSS-Q-80C).

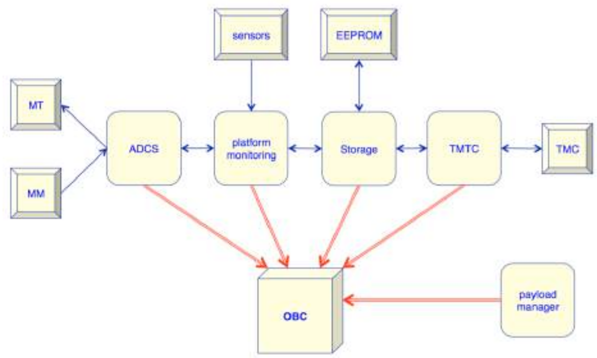

Figure 9: UPMSat-2 software architecture

Ada 2005 was chosen as the main language for the UPMSat-2 on-board software due to its outstanding characteristics for the development of high-integrity embedded systems. In order to properly support the use of Ada and the project requirements, the GNAT Pro compilation chain for LEON3[6] was chosen, together with other Ada related tools, such as the GNAT Programming Studio (AdaCore, a), GNATcoverage (AdaCore, b) and CodePeer (AdaCore, c). The GNAT run-time system includes the Open Ravenscar Real-Time Kernel (ORK), developed at UPM[7]. ORK was designed so as to keep its implementation as simple as possible, focusing on robustness and predictability.

The software (see Figure 9) was developed using a model-driven approach[8]. The production version of the software was developed using the TASTE toolset[9] and other related tools as modeling languages. Simulink (Mathworks®) was used to model the attitude control algorithms, from which sequential C code was automatically generated. The code was integrated into skeleton Ravenscar Ada code generated by TASTE[8].

UPMSAT-2 ASSEMBLY, INTEGRATION AND TESTING CAMPAIGN

UPMSat-2 microsatellite has been developed following a three-model philosophy, based on a Structural and Thermal Model (STM), an Engineering Model (EM) and a Proto-Flight model (PFM).

The STM was used to thermal and mechanically characterize the UPMSat-2 structure and perform measurements of the antennae system (radiation patterns determination). The EM is dedicated to perform functional tests using a spare EBOX (identical to the flight electronic and previously used for the qualification testing of the on-board electronic) and a duplicate of the flight harness.

The PFM was used both for qualification tests as well as acceptance tests. Combining Qualification and Flight Models (QM, FM) of the microsatellite in a PFM saves costs in the development, material and components, but could increase the risk of damaging the flight model during tests. A picture of the EM and STM models of the UPMSat-2, as well as pictures of the Qualification Model of the EBOX are presented in Figure 10.

Next section presents the assembly, integration and testing campaign of the UPMSat-2 summarizing the activities performed and describing the facilities used for each step of the process.

UPMSat-2 Assembly and Integration campaign

The assembly, integration and test phase of the UPMSat-2 started in the beginning of 2019, after the successful completion of the functional tests of the satellite's Engineering Model (see Figure 10) that verified the correct interaction of all components and the software.

Similar functional tests were performed with the satellite's flight harness to verify its manufacturing process.

Figure 10: Upper left picture, the EM model of the UPMSat-2; upper right, the STM model of the UPMSat-2 in the *ground-reflection antenna range* testing campaign; bottom left, the QM model of the EBOX during the mechanical qualification tests and; bottom right, the QM model of the EBOX during thermal vacuum qualification tests

The assembly and integration campaign was carried out in the IDR/UPM integration facilities.

Those facilities are part of the Space Environment Testing Laboratory (LEAE, *Laboratorio de Ensayos en Ambiente Espacial*) and are composed by clean rooms designed to achieve low levels of contamination, in addition to having strictly controlled environmental parameters such as the amount of particles in the air, temperature, humidity, air flow, interior pressure and lighting.

The facilities include an ISO 8 clean room, allowing a maximum of 29,000 particles of size greater than or equal to 5 mm and a maximum of 3.5 x 10^6 particles greater than 0.5 mm per cubic meter. In addition, the LEAE includes an ISO 5 clean room, allowing a maximum of 29 particles larger than 5 mm and 3,500 particles larger than 0.5 mm per cubic meter.

Due to the UPMSat-2 properties, all the integration activities were performed in the ISO 8 clean room.

During the assembly and integration phases, some steps focused on the verification of hardware/software compatibility were performed, as well as functionality checks to ensure the correct interconnection between all the components and equipment.

Some of the steps of the process are shown in Figure 11. In the first and second images, a detail of the upper tray containing the payloads is presented. In the last image, a detail of the ADCS verification tests is shown, carried out to verify the correct integration of the sensors and actuators, as well as the required harness.

Figure 11: Assembly and Integration campaign of the UPMSat-2. From left to right: integration of the payloads tray, integration of the upper tray of the satellite and verification of the ADCS subsystem at the end of the campaign.

UPMSat-2 Testing campaign

The testing campaign of the UPMSat-2 began in 2019 and was performed by a team composed of professors, research staff and students.

For the PFM model of the UPMSat-2, three basic types of tests were performed:

(i) Non-functional tests, for the determination of the satellite mass and center of gravity;

(ii) Functional tests, focused on the verification of the functional requirements of the mission; and

(iii) Environmental tests, focused on two main topics: Mechanical resilience, to ensure that the satellite will be able to withstand the exposure to vibrational loads during launch; and thermal verification, to demonstrate full functionality in vacuum while being operated under hot and cold extreme temperature conditions.

The UPMSat-2 PFM vibration tests (quasi-static, sine and random vibrations) were carried out at the IDR/UPM facilities in 2019 using an electro-dynamic shaker LDS V810 / DPA 20K.

For vertical (Z-axis) mechanical testing, the satellite was mounted on the moving armature (see Figure 5) and, for lateral testing (X- and Y-axis) it was mounted on the shaker sliding table, as shows Figure 12. This picture also shows the post mechanical testing functional verification.

The quasi-static tests consisted of a low frequency (15 Hz) vibration tests with duration of 5 s per axis, and with inputs levels of 8.5 g and 7.7 g for the vertical and lateral directions, respectively. The sine vibration tests were defined between 5 and 125 Hz for each orthogonal axis, with maximum inputs levels of 2.5 g, while the random vibrations tests were defined for the 20-2000 Hz frequency range and inputs levels of 7.5 grms for 1 min for each axis.

Figure 12: UPMSat-2 during mechanical testing campaign in the IDR/UPM facilities.

The successful functional tests performed before and after each structural test demonstrated that the UPMSat-2 was satisfactorily qualified with this severe mechanical environment.

The UPMSat-2 thermal tests[10] were performed in the Thermal Vacuum Chamber (TVAC) of the IDR/UPM, which belongs to the LEAE. It consists of one mid-size vacuum chamber used for testing small satellites and space instruments. Originally, the design of the chamber was driven to be able to test satellites of sizes and morphologies similar to the UPMSat-2.

The TVAC has a baseplate of 700 x 700 mm^2 made of bare aluminum, and a shroud made of stainless steel black painted. The temperatures of the baseplate and the shroud are controlled independently, going from −150 ºC to 150 ºC, by means of liquid nitrogen for cooling and a set of heaters for heating. The vacuum system contains a set of pumps and a cold trap to be able to achieve a final pressure below 10^{-7} mbar.

The thermal test campaign of the UPMSat-2 was performed on the Structural and Thermal Model (STM) as well as the Flight Model (FM) of the satellite. The STM campaign was performed in 2018 and allowed to validate the thermal design through measuring critical parts of the system.

The UPMSat-2 FM Thermal Vacuum Test (TVT) campaign was performed in April 2019 using testing acceptance levels.

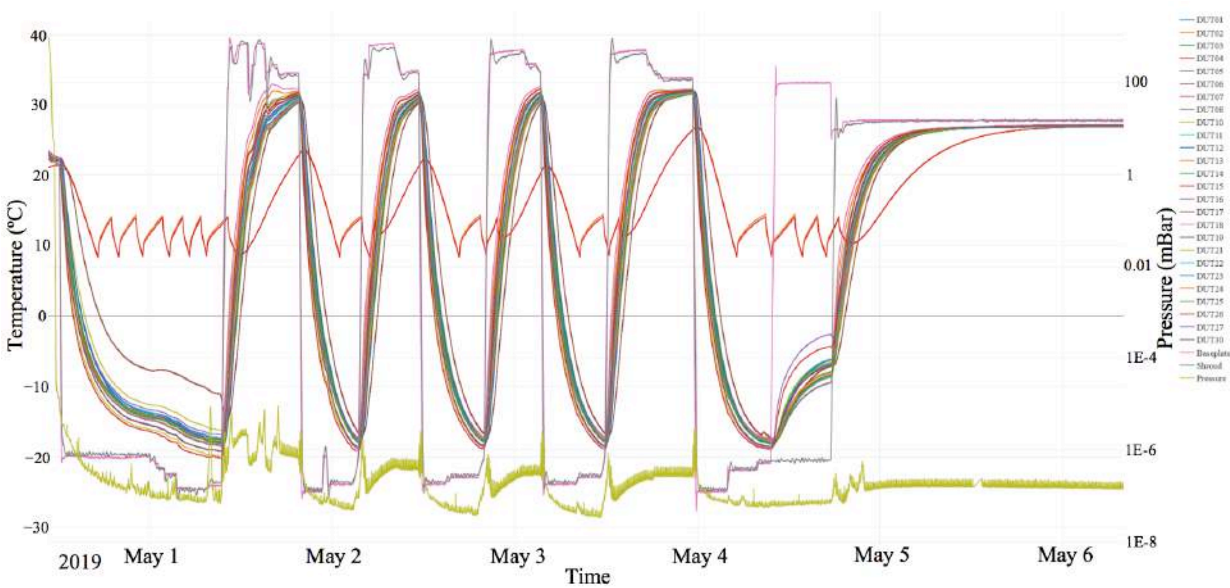

Figure 13: Temperature and pressure values during the UPMSat-2 TVT campaign

The environment temperature was set to +30 ºC and −20 ºC for the hot and cold cases, respectively. In addition to the TVT, two thermal balance phases were done to correlate results with the thermal mathematical model of the UPMSat-2. Testing conditions and measurements recorder for the set of thermocouples spread over the satellite are presented in Figure 13.

Figure 14 shows the UPMSat-2 microsatellite being prepared to start the thermal test campaign.

Prior to the UPMSat-2 thermal tests, some critical equipment as the battery, the E-BOX or the communication board were thermally tested and characterized to reduce the uncertainty in the thermal model and ensure the integrity of the equipment.

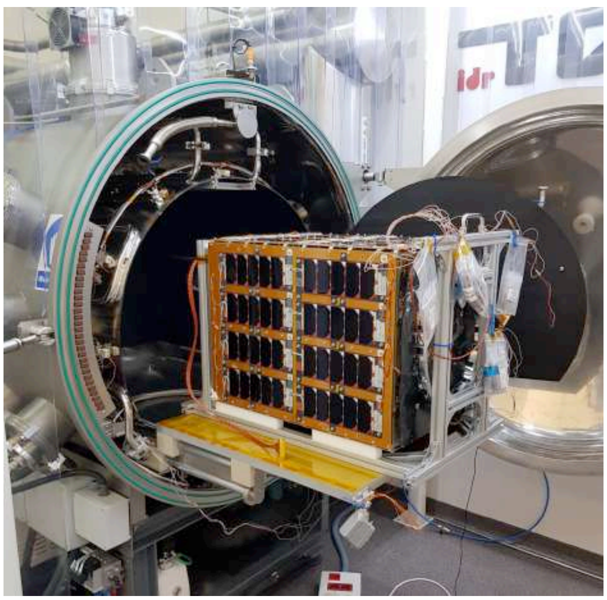

Figure 14: The UPMSat-2 Flight Model during the thermal test campaign within IDR/UPM facilities.

UPMSAT-2 LAUNCH CAMPAIGN AND IN-FLIGHT OPERATION

The UPMSat-2 microsatellite was part of the first European rideshare mission carried out by the Vega launcher, using the SSMS (Small Satellite Mission Service) module. The Vega flight VV-16 was a proof of concept flight were the goal was to demonstrate the capacity to prepare, aggregate, launch and deliver into orbit a set of small satellites.

The SSMS module consists of a dispenser structure able to accommodate a set of payloads to be deployed into Earth orbit, including all the required avionics to program the separation sequences. The dispenser is designed to be modular, so that different configurations of small satellites can be adapted. A picture of the SSMS dispenser of the VV-16 flight is presented in Figure 15.

Figure 15: Small Satellites Mission Service (SSMS) module integrated into the Payload Adapter, just before encapsulation of the Vega Fairing (Image Credit: Arianespace).

The SSMS module is composed a Lower Module Assembly that includes the Hexagonal Module Assembly for the integration of the 46 CubeSats launched in this mission and the Main Deck Assembly where were located the 7 microsatellites. A total of 53 small satellites were launched into space in this VV-16 mission.

Vega's VV-16 launch campaign started in February 2020, for an initially planned launch by end of March. The first weeks of the launch campaign were dedicated to the satellites standalone operations. UPMSat-2 launch team arrived at the Europe's Spaceport in Kourou (French Guiana) on February 18, 2020. First activities were focused on the assembly and integration of the solar panels, which traveled inside an isolated container to avoid damaging the solar cells.

The standalone operations of UPMSat-2 finished after the communication link tests and the charge of the battery up to voltage flight level. Some pictures of the UPMSat-2 standalone operations are presented in Figure 16.

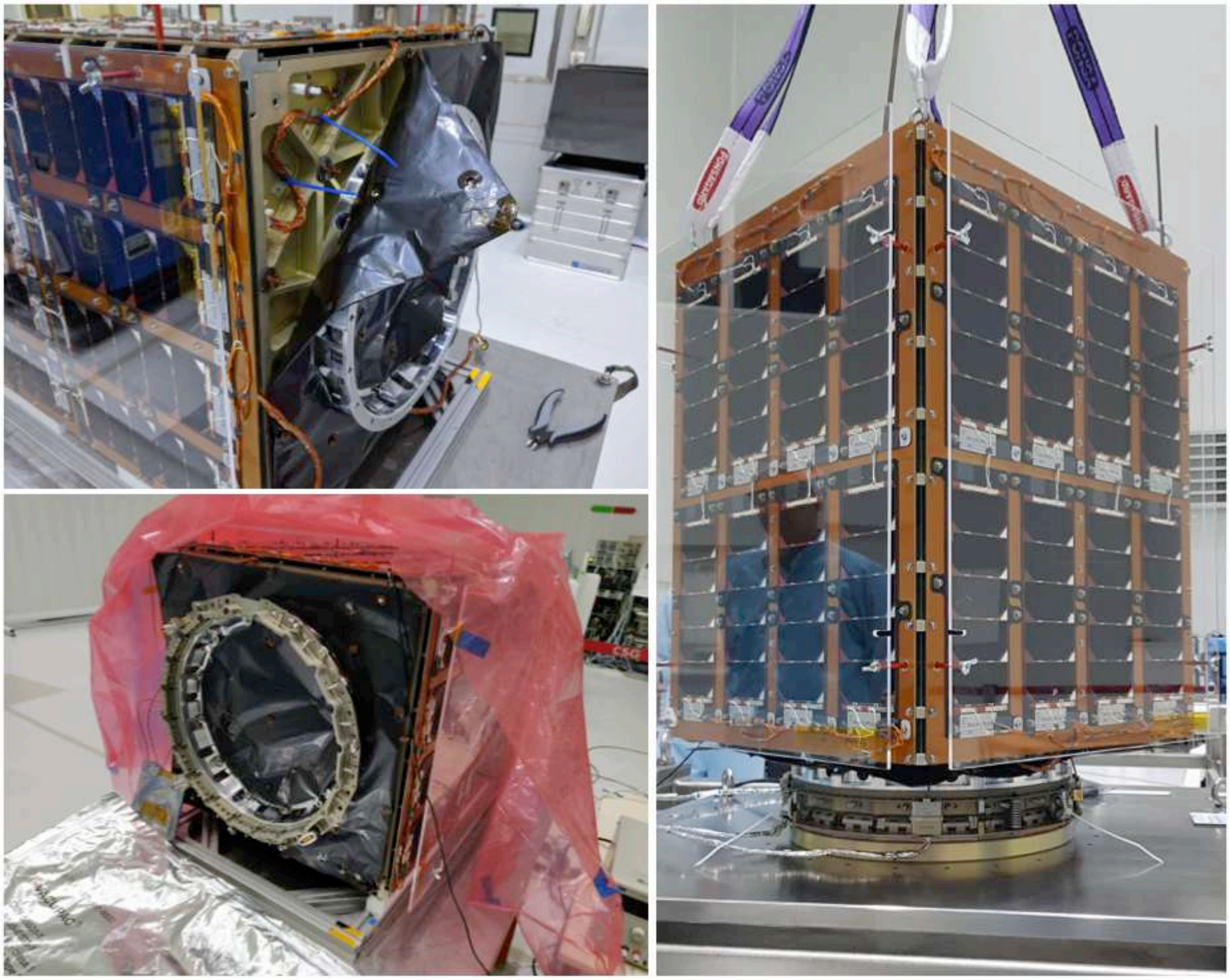

Figure 16: Upper left picture, the finalization of the solar panels flight harness; bottom left, the installation of the upper ring of the separation band (MLB, Mark II Motorized Lightband, of Planetary System Corporations) and right picture, the UPMSat-2 MLB (upper and bottom rings) fully integrated.

After satellites standalone operations, combined operations (integration of satellites into the SSMS module) were planned. Those activities actually started but a few weeks after the launch date, the campaign had to be halted due to measures at Europe's Spaceport to mitigate the COVID-19 pandemic.

Figure 17 shows a picture of the UPMSat-2 microsatellite fully integrated into a Tower Module of the SSMS dispenser.

The launch campaign was resumed on May 11, 2020 but some difficulties derived from the traveling restrictions affected to some of the satellite teams. In the UPMSat-2 case, the battery maintenance, its final charge and the set for flight activities were performed by Arianespace staff.

Smart glasses were used during the UPMSat-2 preparation for flight so that the UPMSat-2 launch team was able to remotely monitor operations conducted on their satellite during August.

Unfavorable weather conditions prevented several launch attempts so Vega rocket and its payloads had to be kept in safe conditions until the final launch date.

UPMSat-2 was finally launched onboard Vega flight VV-16 on September 3, 2020 at 1:51 am (UTC). IDR/UPM team monitored the launch by direct communication with Arianespace launch staff until final separation 40 minutes after the lift off. UPMSat-2 was correctly inserted into the objective sun-synchronous orbit at 500 km of altitude and 97 deg of inclination.

Ground station team started its activities of monitoring and correcting the UPMSAT-2 TLEs (Two-Line Element set) after launch and the first contact was achieved on September 3, 2020 at 11:00 am (UTC).

Since then, UPMSat-2 is in its in-flight operational phase. Flight data and UPMSat-2 status is being monitored and analyzed daily by a team composed of professors and students of the IDR/UPM institute and STRAST group of UPM.

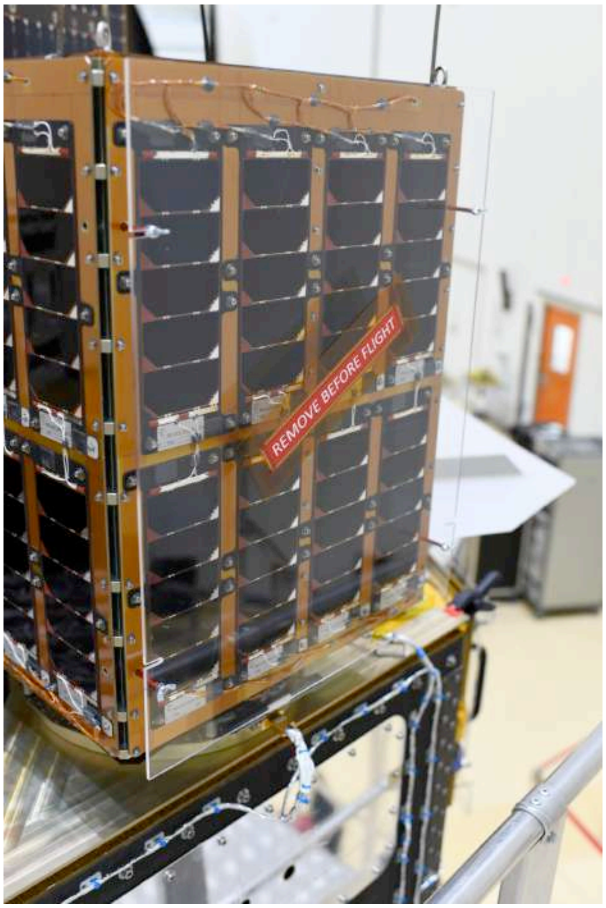

Figure 17: UPMSat-2 fully integrated into a Tower Module of the Vega launcher SSMS dispenser.

CONCLUSIONS

From the educational point of view, the UPMSat-2 mission has proven to be an extremely useful tool for the Master's Degree in Space Systems (*Máster Universitario en Sistemas Espaciales*, MUSE), an official program's master organized by the IDR/UPM institute from the Universidad Politécnica de Madrid.

The different aspects of the mission (design, planning, payload and subsystems analysis, manufacturing, assembly and integration activities, testing, launch and operations) cover almost all the academic load of the master. About a hundred students have participated in the different phases of the project, so the project itself represents a framework that allows students o train their skills in an actual space engineering working environment.

In addition to the educational aspect, the successful launch and operation of the UPMSat-2 microsatellite has strengthened the ability of the IDR/UPM research institute and STRAST group of fully develop a satellite. The UPMSat-2 team is involved since September 3 in the operation of the microsatellite allowing the in-flight qualification of the platform and some of the payloads.

In addition, the project has allowed the development of models, tools, software, environmental testing facilities, and a ground station that indeed have become educational tools of first level for UPM students.

The benefits of this type of projects are clear, so the IDR/UPM institute is already planning a new microsatellite mission for being used as educational platform of the new generations of students.

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