Athens Journal of Technology & Engineering 2023, 10: 1-21
https://doi.org/10.30958/ajte.X-Y-Z

The UPMQube: An Academic/Educational PocketQube Proposal for the EU2Space Challenge

By Elena Roibas-Millan[*], José Miguel Álvarez-Romero[±], Sergio Marín-Coca[°], Ángel Porras-Hermoso[•], Javier Pérez-Álvarez[♦], Javier Cubas[♠] & Santiago Pindado[♣]

In the present paper, the UPMQube PocketQube proposal for the EU2Space challenge is described. This proposal has been developed by a group of master's degree students led by Ph.D. students and professors from the Instituto Universitario de Microgravedad "Ignacio Da Riva" (IDR/UPM) at Universidad Politécnica de Madrid (UPM). PocketQube is a recent new picosatellite concept, which is currently under development. Its reduced size and mass require a significant effort to reduce the characteristic size of the elementary subsystems. One of the subsystems that offers the greatest capacity for improvement is the Attitude Determination and Control Subsystem (ADCS), since most PocketQubes do not usually have one due to lack of space. The most relevant technical aspect of this proposal is the development of a new ADCS which fits the high restrictive size and mass requirements, and it is based on Commercial Off-The-Shelf (COTS) components. This ADCS is composed by: (i) a purely Autonomous Magnetic Controller (AMC) based on magnetorquers and magnetometers on board the spacecraft (S/C platform; (ii) an Attitude Determination System (ADS) based on solar sensors and thermal sensors on board the S/C and an On Ground Attitude Determination Algorithm (for post processing the sensors flight data. The work carried out by Master s degree students is integrated within the academic program of the UPM's Master in Space Systems as a Case of Study. It also provides an excellent training program for the Ph.D. Assistant Professors included in the proposals Team. The tasks assignments and responsibilities of all members of the Team are fully described in the paper. Additionally, it should be underlined that this proposal is quite well balanced in terms of gender, as 40% of the Team (including the Principal Investigator) are women. This figure is higher than the mean percentage of women present in STEAM Sciences, Technology, Engineering, and Mathematics careers (29% of the workforce, 19% of company board members, 3% industry CEOs).

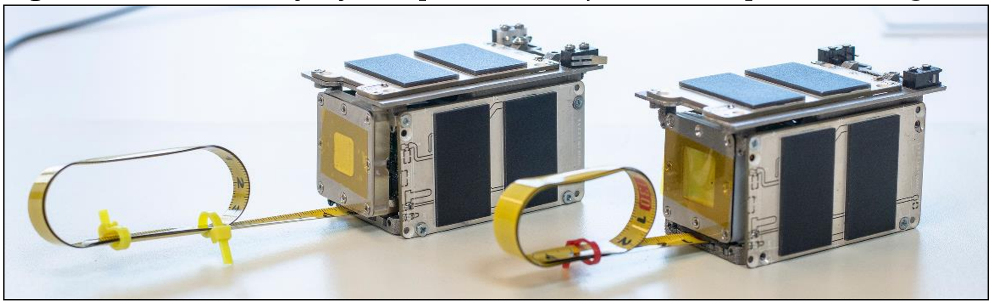
Keywords: *UPMQube, PocketQube, MUSE, magnetic ADCS, space engineering challenge*

[*]Professor, ETSIAE - Polytechnic University of Madrid, Spain.
[±]Researcher, ETSIAE - Polytechnic University of Madrid, Spain.
[°]Professor, ETSIAE - Polytechnic University of Madrid, Spain.
[•]Researcher, ETSIAE - Polytechnic University of Madrid, Spain.
[♦]Professor, ETSIAE - Polytechnic University of Madrid, Spain.
[♠]Professor, ETSIAE - Polytechnic University of Madrid, Spain.
[♣]Professor, ETSIAE - Polytechnic University of Madrid, Spain.

Introduction

The PocketQube (see Figure 1) is a recent concept of picosatellite currently under development. Its main advantage is its small size, with dimensions of only 5x5x5 cm in its smallest version (one unit). Due to its limited size, the mass is also very small, barely 250 g per unit. The concept was devised in 2009 for educational purposes, and the first PocketQube was launched into space in 2013. By mid-2021, 13 missions had been launched into space, with more than 40 in development (Yost et al. 2021). Its main advantage lies in its low mission costs, which can be in the $20k range including development, testing, and launch (other formats such as CubeSats multiply that price by at least 8). Due to this reduced cost, they have become popular for start-up companies or academic projects. PocketQubes also have some drawbacks. For one, they are less popular than the standard CubeSat, so there is much less hardware available on the market. Most of the one used is Commercial Off-The-Shelf (COTS). They also have much less space to place it, so the capabilities of these satellites are still much smaller.

Figure 1. *PocketQube by Hydra Space Studied for the EU2Space Challenge*



PocketQubes have a very promising potential for use in space education. On the one hand, its prices are more affordable than other larger Cubesat standards. But its main advantage would be that the project times, between one and two years, are very suitable to be integrated within the academic deadlines of a university master's degree. Being able to include all phases of the project, from design to operation, including integration and testing, within a single academic promotion.

The master's degree in space systems at UPM has recently had the opportunity to become familiar with this new standard thanks to the EU2Space program, a challenge for Spanish students that encourages them to build their own satellite and put it into operation in space. Several of the MUSE teachers, belonging to the educational innovation group INNAERO (*Innovación Educativa en Ingeniería Aeroespacial*) have decided to test the possibilities of this standard within the academic program of the master. This document puts the activity in context, explaining the characteristics of the master and the challenge. As well as the way in which the challenge has been integrated with the various subjects of the master. All this with the idea of multiplying the chances that students will be able to successfully put the satellite into space and motivate them with exciting projects and tangible results within a project-oriented educational program.

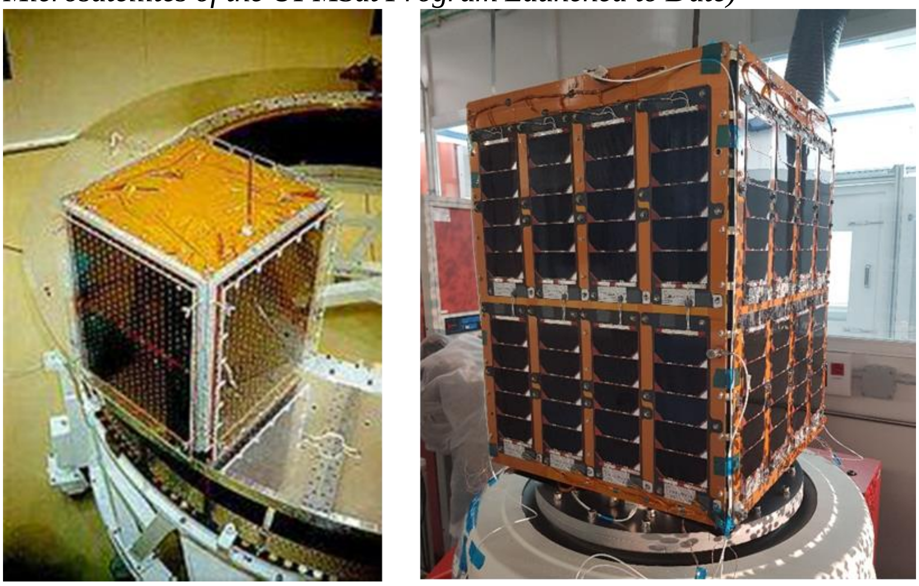
Overview of the Master in Space Systems (MUSE)

The Master's degree in Space Systems (MUSE) is a 120 ECTS (two years) master designed to provide a practical approach to space systems technology and research activities in space sciences (Pindado Carrion et al. 2017, Pindado et al. 2016, 2018).

MUSE is organized, managed, and supported by the *Instituto Universitario de Microgravedad "Ignacio Da Riva"* (IDR/UPM). The IDR/UPM Institute is one of the 5 Research Institutes of the *Universidad Politécnica de Madrid* (UPM), and its main activities include applied aerodynamics, wind engineering and space technology. The IDR/UPM Institute has participated in several space missions including NASA and ESA's interplanetary spacecrafts. The contributions made frequently include the thermal and structural design of instruments and subsystems. More recently also mission analysis and attitude determination and control subsystem (ADCS) design have been included among the priorities of the institute. Among the historical missions in which the IDR/UPM Institute has participated, the ESA Rosetta – Osiris mission stands out, the first mission to land on a comet. Missions currently in operation in which the institute has participated include Solar Orbiter, such as the PHI and EPD instruments, ExoMars (TGO - NOMAD). Some of the future missions that the IDR/UPM Institute participates in are Euclid and Ariel (Sanz-Andrés and Meseguer 2006).

Another of the space engineering activities carried out at the IDR/UPM Institute is the launch and operation of microsatellites oriented to educational, scientific, and technological demonstration applications (see Figure 2). These satellites are usable as an in-orbit technology demonstration platform. These missions improve and expand the knowledge of teachers, students participating in the project, and demonstrate the capacity of the UPM in the field of space technology (Pindado Carrion et al. 2017, Sanz-Andrés et al. 2003).

Figure 2. Left: *UPMSat-1 (1995)* and Right: *UPMSat-2 (2020) (The Two Microsatellites of the UPMSat Program Launched to Date)*



A key aspect of the Master in Space Systems (MUSE) is the use of a Project Based Learning (PBL) approach, taking advantage of the experience of the IDR/ UPM Institute in space projects and microsatellite development. PBL main goal is to provide students with the opportunity to apply their knowledge, not just acquire it (Brodeur et al. 2002), focused on the students learning, making them co-creators of their own education. PBL also prepares students with some specific skills, such as curiosity, creativity, and collaboration, and is especially interesting for master students, who have already acquired a solid theoretical foundation.

The master course is classified into theoretical and practical lessons related with space technologies, classified into five different group (see Table 1).

Table 1. *The Five Groups of Subjects Included in the Master of Space Systems (UPM), Classified by Type of Learning (Mono-Disciplinary or Multidisciplinary + PBL)*

Group	Total ECTS	Learning methodology
Advanced Mathematics	12.0	100% Mono-disciplinary
Spacecraft Subsystems	28.5	53% Multidisciplinary + PBL
Space Projects Definition	22.5	60% Multidisciplinary + PBL
System Engineering	25.5	30% Multidisciplinary + PBL
Case Studies and Final Project	31.5	100% Multidisciplinary + PBL
	120	**55% Multidisciplinary + PBL**

In Table 2 and 3 a list of the subjects that make up each semester of the muse can be found. Those that will take part in the EU2Space challenge are highlighted in bold.

Table 2. *Subjects of the First Course of the Master MUSE*

Semester	Subject	ECTS
1st	Advanced mathematics 1	6.0
	Space environment and mission analysis	3.0
	Systems engineering and project management	6.0
	Vibrations and aeroacoustics	4.5
	Graphic engineering for aerospace mechanical design	4.5
	Space propulsion and launchers	4.5
2nd	Advanced mathematics 2	6.0
	High speed aerodynamics and reentry phenomena	3.0
	Heat transfer and thermal control	6.0
	Electric power generation and management	3.0
	Spatial use structures	4.5
	Case study (1)	1.5
	Communications	4.5
	Data management	4.5

Table 3. *Subjects of the Second Course of the Master MUSE*

Semester	Subject	ECTS
1st	**Orbital dynamics and attitude control**	4.5
	Space Use Materials	4.5
	Quality guarantee	4.5
	production technologies	4.5
	Integration and tests	4.5
	Case study (2)	7.5
2nd	Seminar on space industry and institutions	1.5
	Case study (3)	9.0
	Master's thesis	18.0

MUSE's students participate in real-life projects of IDR/UPM. This has the advantage of providing hands-on experience and motivation to the students. But also has certain challenges, like the harmonization of the education and projects.

One of the difficulties that a PBL-based master is finding motivating ideas for student projects, which are also realistic and prepare them for their professional activity. When choosing these projects, the IDR/UPM Institute has usually resorted to its experience in projects, highlighting two types of activities:

Academic Projects based on IDR/UPM Institute's Activities in Scientific Instrumentation

The inclusion of students in the international projects in which the IDR/UPM Institute participates is usually reserved for individual work and the most advanced Study Cases. Normally in the second year of the master. These projects have important pros: students are highly motivated to work on important missions; and represent a more realistic approach to the labor market (including handling requirements, regulations, etc.). But it also has some cons: there are not always enough projects for all students; it is difficult to adjust deadlines to the master academic times; and the topics covered in these projects do not include all the themes of the master.

Increasingly frequently, students carry out these individual and advanced case studies in companies or institutions other than the IDR. This possibility is encouraged in the master and has similar advantages to the aforementioned projects. With the additional advantage that the topic can be much more varied. Although this is only applicable for individual case studies.

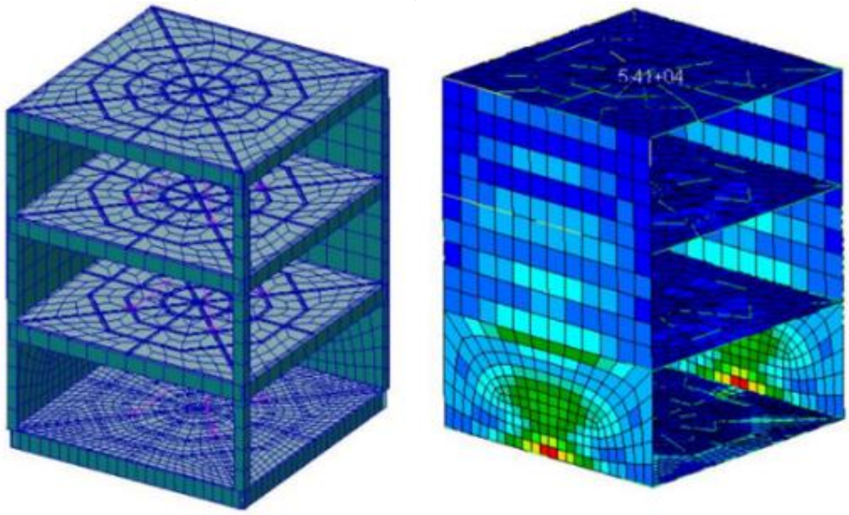
Academic Projects Based on the IDR/UPM Institute's Microsatellites Program

The second main source of student projects for MUSE is the UPMSat project. The IDR/UPM Institute microsatellite project was resumed in 2014 at the same time as the MUSE master was organized, with the intention of involving students in the development of UPMSat-2. From the beginning of MUSE to the present, all MUSE promotions have participated in the development of UPMSat-2. The first promotions participated in the design, the following ones in manufacturing and testing. Since its launch, the latest promotions have participated in its operation. This project has turned out to be one of the successes of the Master, and its results have been commented on in several publications (Pindado Carrion et al. 2017). Among the advantages of this project is that students are motivated to know that they are contributing to something that will be in space; and unlike other projects at the IDR/UPM Institute, this one includes all the topics of the master, and it includes all phases of a project (design, manufacturing, qualification...). Finally, the microsatellite program has contributed to train both students and teachers in an overview of space systems. Since without their help, many of the master's teachers would only have had a theoretical approach to the subject they taught.

Specific problems in the development of the UMSat-2 such as thermal design, access analysis to the ground station, mechanical tests, etc. were a source of individual work for many MUSE's case studies. But on the other hand, the lessons learned, and the procedures developed have also been a source of inspiration for the PBL group projects of the MUSE subjects. Notable examples are satellite integration, satellite wiring, solar panel testing, structural design (see

Figure **3**), or the development of attitude control laws; all these activities have been proposed as group projects for different subjects to the master's students in several successive years.

Figure 3. *Finite Element Method Model of the UPMSat-2 and Structural Analysis Results Obtained by MUSE Students. Project Proposed to Students in the Subject Space Structures (Cubas et al. 2022)*



Academic Projects Based on Academic Challenges

There is a third source of projects for students who participate in MUSE: the Challenges or international competitions for students. On a recurring basis in the

MUSE master, different competitions have been integrated into the academic program. These competitions, whenever possible, have been held with universities from other countries. In this way, a double effect has been achieved on the students. On the one hand, the challenges have had the ability to motivate students and provide them with typical PBL skills. On the other hand, by participating with students from other universities and countries, it has allowed them to contact groups of other nationalities and cultures. Improving their interaction skills in international environments and languages other than Spanish (the language in which the master is taught).

This point, and how it is integrated into the master, will be further explored in this article.

Academic Challenges Conducted in the MUSE

Some of the most representative activities in which MUSE students have participated are listed below.

The 1st ESA Academy Concurrent Engineering Challenge

Between September 12th and 15th of 2017, ESA Academy conducted the 1st *ESA Academy Concurrent Engineering Challenge* as an extension of ESA educational programs oriented to concurrent engineering. The objective of the challenge was to design a satellite to look for Moon Surface areas that could be used as locations for a future human base. Students of four different institutions were invited to participate simultaneously in different CDFs. MUSE students from *Universidad Politécnica de Madrid* (Spain) were one of the selected groups, the other groups were from the ESA Academy's Training and Learning Centre at the European space Security and Education Centre (ESEC) in Belgium, students from *Politecnico di Torino* (Italy) and students from University of Strathclyde (United Kingdom). The challenge itself was not a competition but an opportunity to share the progress, raise any difficulties receive helpful input from the other participants. At the end of the challenge each group presented their final design. The result of this challenge was the mission MEOW presented in Figure 4 (Roibás-Millán et al. 2018a).

Additionally, a MUSE student participated in the 2nd *ESA Academy Concurrent Engineering Challenge*, which was held from 22nd to 26th October 2018 (see

Figure **5**). This student was invited to be part of the ESA Academy's team. After coming back this student said "This event gave me and other 29 students from different nations the opportunity to preliminary design a mission following ESTEC procedures. The work carried out by us was not only focused on each subsystem but also harmonized with the whole group of them and directed towards one single final objective: the success of the mission. Although in the Master in Space Systems (MUSE) the Concurrent Design (CD) concept is embraced, during this week working in ESA facilities I managed to understand the basics of the philosophy that remains behind the CD procedures. This was possible thanks to the experts from the European Space Agency (ESA) that dedicated all their attention to us from the first iteration till the last modification of the designed mission. We developed SANTA mission (Satellite for Airborne and Naval Transmission in the Arctic) using 12 subsystems. I had to study the power requirements, analyze the different options related to the power subsystem (solar panel, battery…) and select the best viable option. This was, in my opinion, the best experience directly related to space engineering I have had".

Figure 4. *MEOW Spacecraft. (1) Main thruster, (2) Attitude Control Thrusters, (3) Deployable Solar Panels, (4) Orientable X-band Antennae System, (5) Launch Adapter Ring. S-band Patch Antennas and Sensors are not Shown in the Image (Roibás-Millán et al. 2018a)*

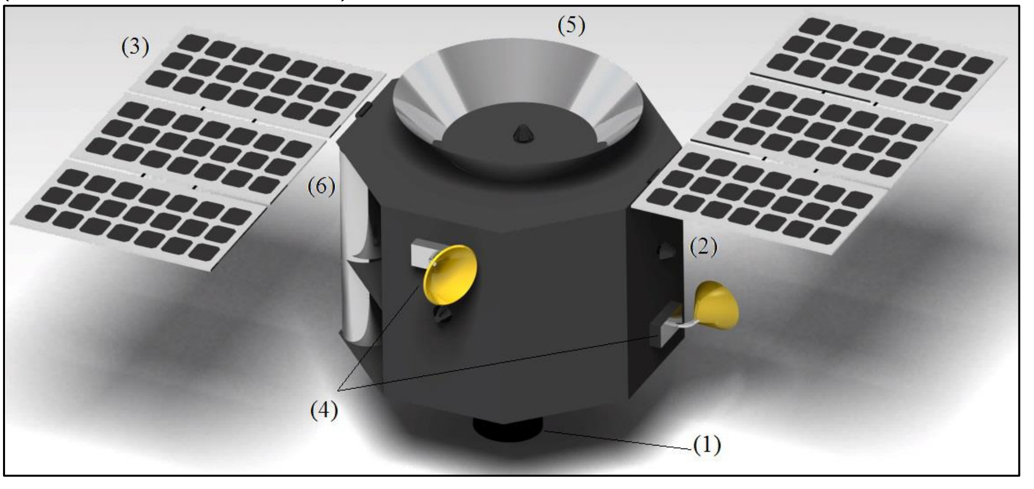


Figure 5. *The MUSE Student Borja Cobo López at the ESA Academy during the 2nd ESA Academy Concurrent Engineering Challenge*

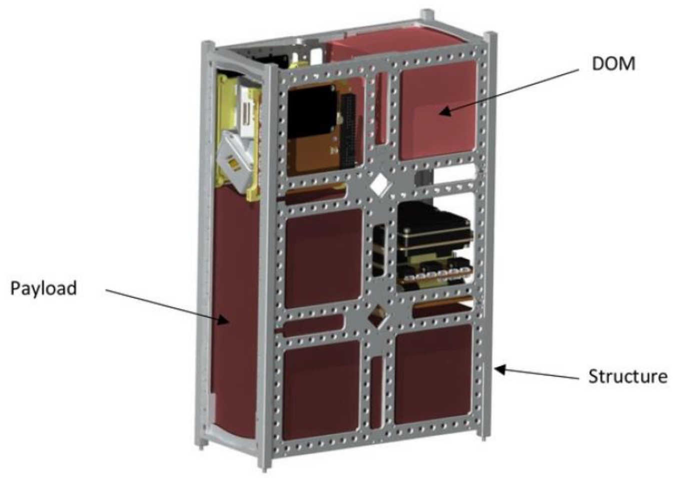
The NANOSTAR's Challenges

NANOSTAR (Monteiro and Guerman 2020) was a project funded by the *Interreg Sudoe Programme* for creating a network of excellence among universities, the regional industry, and the scientific ecosystem in order to increase the European knowledge on nanosatellites. The consortium was composed of 7 universities and 2 aerospace clusters, plus 3 ESA Business Incubation Centers as associates, in France, Spain and Portugal. All the results of the project are open source and can be found in Gitlab repositories (Nanostar 2021a, 2021b).

Among the activities of the consortium was the organization of two challenges in which groups of students from most of the participating universities competed. The first NANOSTAR challenge (2019) consisted in the predesign of a nanosatellite/small satellite space mission to the Moon. The second one (2020) aimed at predesigning a nanosatellite that is built around a scientific based space mission. In each of the editions, around four teams of MUSE students participated (see

Figure 6) obtaining various awards.

Figure 6. *Image of the nanoMUSE Mission, One of the Missions Proposed by the MUSE's Students During the Second NANOSTAR Challenge. The Objective of the Mission was to Maintain Alive a Colony of Roscoff Worms*



The 2021 Challenge: EU2Space

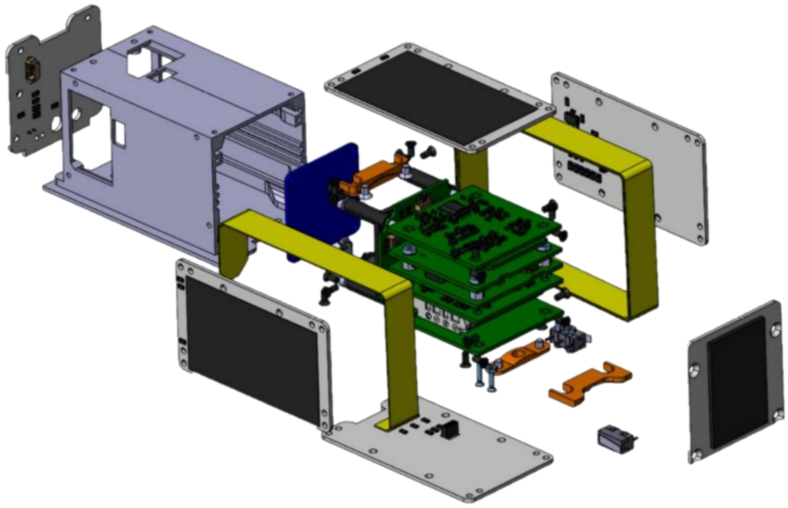
The Europe to Space (EU2Space) Challenge[1] allows university students to work on a real satellite development mission in all its phases, including launch and subsequent operations. This Challenge, promoted and organized by UARX Space, Hydra Space and AMSAT EA, started its first edition in September 2021 and has three stages. The first is a course with specific content, which serves as support at an introductory level for those who have no experience in space. It will give students the necessary tools to understand and design a real mission. In the case of MUSE students, this has served to reinforce their knowledge. At the end of this

[1]https://www.eu2space.com/.

phase the students propose different mission concept, and the selected groups go to the next phase.

The second phase focuses on the creation of the mission. Organizers provides with an educational kit (see Figure 7), based on the PocketQube standard, satellites weighing about 350 grams. The kit includes everything needed to have a platform capable of going into space, which will allow students to learn, modify, test, expand or even replace components to achieve the mission they propose. It will consist of an on-board computer (OBC), a communications system, including radio frequency and antenna components, a satellite structure, a power subsystem to generate, regulate and store energy, a well-defined interface to enable the inclusion of a payload and the necessary ground support equipment. Currently, the challenge is at the beginning of this second phase.

Figure 7. *Preliminary Design of the Satellite's Kit (UARX Space n.d.)*



The third phase will focus on obtaining the funds to pass the exhaustive tests to reduce the risk of failures and bear the launch costs. For this phase, the students will have to look for sponsors, until covering the costs of the mission. Which will also be an important challenge and will certainly help students to acquire truly relevant skills. For example, if they decide to entrepreneurship. The IDR/UPM Institute will support the master's students in this work, and it is expected that part of the costs can be reduced by carrying out certain tests in the IDR's testing facilities.

This challenge is organized by the following Spanish entities: UARX Space, a space logistics company that provides shared and dedicated launch solutions for small satellites; Hydra Space, a company specialized in PocketQubes and CubeSats, developed entirely in Spain to provide solutions for global IoT, and AMSAT EA, a non-profit cultural association dedicated to the study, dissemination of information and the promotion and development of space satellites for the communication of the Amateur Radio Service.

Although the EU2Space challenge was attended by more than 400 students, only 10 teams have been selected to participate. Of the 10 selected teams, three are made up entirely or mostly of students from the ETSIAE of the Universidad Politécnica de Madrid. The selected teams that belong to the UPM are UPMQube, Horizon and Caronte Crew.

MUSE Students' Proposal to EU2Space

The project corresponding to the students of the MUSE master is the UPMQube (see Figure 8) whose characteristics are detailed below.

Figure 8. *Mission Patch for UPMQube Project*

Mission Concept

As mentioned before, the reduced size and mass of PocketQubes require a significant effort to reduce the characteristic size of the elementary subsystems. One of the subsystems that offers the greatest capacity for improvement is the Attitude Determination and Control Subsystem (ADCS), since most PocketQubes do not usually have one due to lack of space. In addition, adapting commercial ADCS (even the one for CubeSats) for its use in PocketQube platforms is a meaningful challenge. In fact, even the smallest ADCS are too heavy and large to be used on PocketQube platforms.

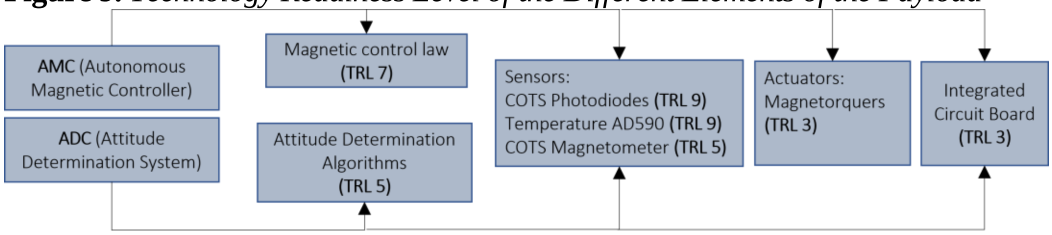
Among all existing ADCS strategies, magnetic attitude control is one of the most attractive alternatives for the attitude control of small satellites with not-too-demanding orientation requirements. This strategy significantly saves overall power and reduces weigh, cost, and the system's complexity compared to other attitude control options. In addition, the risk of failure is reduced, making the system more reliable. All advantages make magnetic attitude control well suitable for picosatellites operating in Low Earth Orbits (LEOs).

For those reasons, the proposal of UPMQube is an ADCS based on Commercial-Of-The-Shelf (COTS) elements that can be adapted to PocketQubes as small as 1.5P. To achieve this goal, the complete ADCS is divided into two payloads: (i) an autonomous magnetic controller (AMC) based on magnetorquers and magnetometers on board the S/C platform and (ii) an attitude determination system (ADS) based on solar sensors and thermal sensors on board the S/C.

The AMC main characteristics are the following: (1) only magnetorquers are required as actuators, (2) only magnetometers are required as sensors, (3) it does not need an on-orbit Earth magnetic field model, (4) it does not need to be externally activated with information about the orbital characteristics, and (5) it allows automatic reset after a total shutdown of the attitude control subsystem.

The attitude control proposal is closely related to the teaching of the subjects taught in the master, since it is a master in space systems. The students took many lessons learned from the UPMSat-2 project and its attitude control (Zamorano et al. 2017). The use of the UPMSat microsatellite program in the MUSE has already been treated in other papers in other editions of ENGEDU (Pindado Carrion et al. 2017). This program has not only laid solid foundations in the training of students and teachers of the master but has also managed to raise the Technology Readiness Levels (TRLs) of many of the technologies that will be used in this mission (see Figure 9). Including magnetic attitude control laws (Cubas et al. 2015), magnetometers calibration (Rodríguez-Rojo et al. 2019a), magnetorquers essays (Rodríguez-rojo et al. 2019b), solar sensors design and operation (Porras-hermoso et al. 2021b), an others.

Figure 9. *Technology Readiness Level of the Different Elements of the Payload*



Team Composition

Most of the group is composed by 15 members with a bachelor's degree in Aerospace Engineering and one with bachelor's degree in Mechanical Engineering. All of them currently enrolled in the first year of the master's degree in Space Systems at the Universidad Politécnica de Madrid (UPM).

The group is completed by three doctoral students, former students of the MUSE master's degree, who are currently carrying out research work at the IDR institute. In this way, most of the work will be carried out by the first-year students, but the various shortcomings that they may still suffer from due to not having completed all the subjects, are complemented by the greater experience of the doctoral students.

This combination of first-year students with second-year or doctoral students tutors is a strategy that we have used very frequently in the MUSE's case studies and has always given us satisfactory results.

As all the members of the Team are currently enrolled in a MSc in Space Systems, or are PhD students in Aerospace Engineering, all the technical aspects for the payload design, manufacturing and testing can be overcome by the Team members. In terms of gender, the Team is well balanced. The number of women participating in the Team is even higher than the mean percentage of women present in STEM careers. Indeed, the principal investigator is a woman (Professor) of the UPM with extensive experience in the space sector.

Integration of the Challenge with the Academic Activities of the Master

As aforementioned, MUSE's academic program is centered around a Project-Based Learning (PBL) methodology, as a comprehensive perspective focused on teaching by engaging students in research and resolution of authentic problems. Involving students in actual engineering projects allow them to learn by doing, taking advantage of the two essential components of a project: they require to solve a question or problem that serves to organize and drive activities, and then these activities result in a series of products, or solutions, which culminate in a final product that addresses the driving question.

An observed effect of PBL application is that students connect with their own learning process, gaining ownership over their learning. Consequently, the student's interest and motivation are highly increased. Another advantage of applying PBL is that enable an effective collaboration between industry and universities. This collaboration has mutual benefits because it has the potential of create a steady talent pipeline, providing graduates with a direct pathway to the workforce.

Within MUSE academic program, students participate in research projects conducted by IDR/UPM professors and staff. However, it is usual that they can only contribute in some project phases due to time limitations. Traditionally, space projects had extremely long-duration development stages, from identifying the need up to place the satellite in the right orbit to perform its operation. The new space era has changed this paradigm and the new goals are to be agile, responsible, and therefore far less expensive. One consequence is the reduction of the project size by using, for example, CubeSat platform or even the smaller PocketQubes.

The latter are interesting platforms to be using in an academic environment. On one side, the development times are short and on the other, the project cost is affordable for research institutions and universities. In this context, participating in the EU2Space challenge is a fantastic opportunity for MUSE students, as they can take part of an entire satellite project from the conception up to the launch and operation.

Furthermore, after the launch of UPMSat-2 in 2020, and pending the completion of the new mission for UPMSat-3, the IDR/UPM is currently without an ongoing development of a satellite on which the students can work. The EU2Space project has therefore been an interesting opportunity to provide a more detailed practical component to the formation of the master's students.

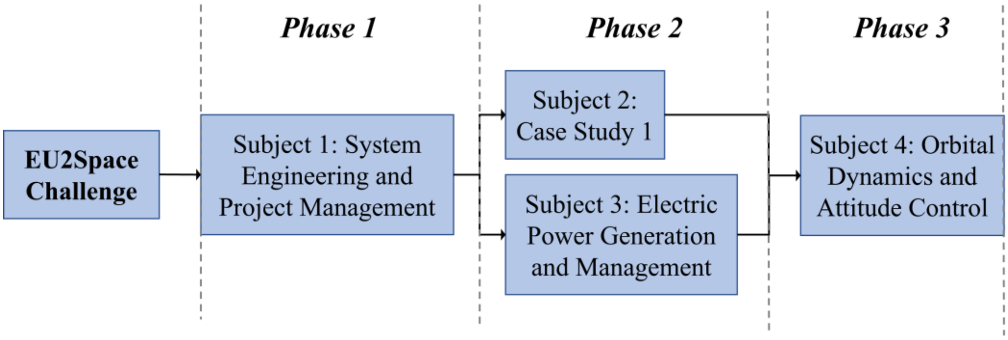
However, integrating a real industry-led project in an academic environment is a major challenge. First, the time that students can dedicate to the challenge is limited as they are immersed in their respective subjects. To be able to give students the time to participate in the challenge without compromising the acquisition of competencies, a great adaptation effort must be performed by the professors regarding the subject's schedule and planning. One of the greatest successes has been the adaptation of the subjects, so that the theoretical contents can be taught within the framework of the challenge. Therefore, the EU2space challenge has been incorporated into the activities of the master, as a motivating element for the projects proposed to the students.

For this reason, several of the master's subjects, which extend over three semesters, have adapted the activities proposed to students to be complementary to the challenge. In this way, it is expected to reduce the workload, already very extensive without counting on the challenge, that the students have; in addition to academically rewarding the effort of the students.

To integrate the challenge schedule within the academic MUSE program, the activities are articulated around certain subjects, in a three-step process that is shown in

Figure **10**.

Figure 10. *Three-Step Process to Integrate the EU2Space Challenge in MUSE Academic Program*



The process is described as follows:

- *Phase 1*: This phase is carried out within the 1st year, 1st semester MUSE subject "System Engineering and Project Management" (see Table 2). In the last years, this subject has included relatively new concepts and trends in space mission predesign and feasibility phases (Roibás-Millán et al. 2018b).
  Between others, Concurrent Engineering (CE) has revealed as a design philosophy that facilitates the design process by using tasks parallelization (instead of the traditional sequential design), and therefore improving the flux of information between disciplines by working in a collaborative environment.
  IDR/UPM has its own Concurrent Design Facility (CDF), which includes the technology and resources needed to perform parametric studies, aiming

to find a mission solution that fulfils the technical requirements in a brief period (usually less than a week).
Within this subject, students are guided in a Concurrent Engineering process within the CDF (Pindado et al. 2021a). A mission is proposed in base of a set of requirements, so a preliminary design is requested as an output of the work. Usually, students are distributed in two or three teams, each one of them performing the same mission design. Therefore, the results obtained by each team can be compared and analyzed by collaborative sessions within the classroom.
This academic year, the CE project was oriented to the PocketQube mission, so students were divided in two groups, each one of them developing a proposal for the PocketQube payload. Results and conclusions of both teams were analyzed and condensed into a single proposal to be presented to the challenge call.

- *Phase 2:* The second phase of the process is devoted to the development of the payload by transforming the preliminary design of the previous phase into a detailed design. This phase is articulated around two MUSE subjects, both of 2nd year and 2nd semester, "Case Study 1" and "Electric Power Generation and Management" (see Table 2).
Within "Electric Power Generation and Management" students must perform an analysis of the behavior of the PocketQube under operating conditions (see next section) to derive the in-orbit power availability for the payload. Then, "Case Study 1" is oriented to define the interfaces between the payload and the PocketQube platform kit and develop the electric/electronic design of the proposed payload. This analysis includes selection of sensors (thermal sensors, magnetometers, and photodiodes) and actuators and the design of the signal conditioning circuits.

- *Phase 3:* Finally, the objective of this phase is to develop the experiments of the payload, in this case the control laws that will be tested onboard the satellite. This task will be carried out in the subject Orbital dynamics and attitude control, first semester of the second year (see Table 3). By this time students are expected to have a good understanding of the satellite's attitude control system. Therefore, after receiving training in this regard, they will be able to develop control laws, model their operation and anticipate their behavior in flight. The students will be distributed in groups and the project that will be carried out during the subject will include tasks such as the modeling of the ADCS, the environment, and the behavior of the control laws. As a result of the students' work, it is expected that several control laws, adequate for a satellite with the characteristics of the PocketQube, will be obtained. These laws will be tested during the mission.

Detailed Example for One Subject: Electric Power Generation and Management

This section summarizes the project based on the EU2Space project proposed to the students of the subject Electric Power Generation and Management. This will allow the reader to get an idea of the detail of the proposed problem, the evaluation criteria, as well as the skills that are intended to be fostered with the proposed work. It also summarizes how the work is included within the rest of the projects of the subject.

Students of the power systems course (Pindado et al. 2018) will perform an analysis of the behavior of the HydraSpace PocketQube under certain operating conditions and will seek to analyze the effects of the different parameters considered in the mission.

This work has been preceded by three others:

- Analysis of the maximum power extractable from the Sun by a microsatellite similar to UPMSat-2 (Pindado et al. 2017), placed in a sun-synchronous orbit. It was proposed to study the maximum extractable power as a function of the angle between the plane of the orbit and the solar direction, the altitude of the orbit, and the energy efficiency of the solar cells that make up the solar panels.
- Simulation of the behavior of a solar panel as a function of its operating point, radiation, and temperature.
- Simulation and analysis of the behavior of a battery, applying the models developed at the IDR/UPM Institute (Pindado et al. 2021b).

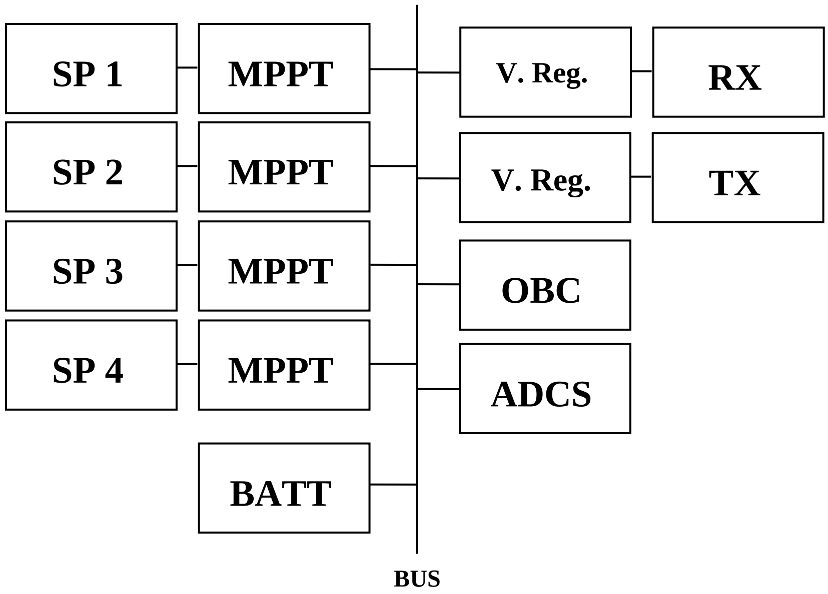
The power subsystem of the PocketQube from HydraSpace has been simplified into the following parts (see Figure 11):

- 4 Solar panels, each one with its own Maximum Power Point Tracking (MPPT) system.
- 1 Li-ion battery.
- 1 signal transmitter and 1 signal receiver, both equipped with its own voltage regulator.
- 1 On-Board Computer (OBC)
- 1 Attitude Determination and Control Subsystem (ADCS).

Operation conditions are grouped are organized in the following group of constraints:

- Orbit and attitude.
- Solar panels and MPPT.
- Battery.
- Attitude Determination and Control Subsystem (ADCS).
- Voltage regulators.
- Power consumption.
- Operational modes.

Figure 11. *Sketch of the Power Subsystem of PocketQube by HydraSpace Studied for the EU2Space Challenge*



Orbit and Attitude of the Mission

The PocketQube will flight in a 550 km altitude helio-synchronous orbit, the angle between the orbit's plane and the Sun direction being 0º (noon orbit), 22.5º and 45º. Three different attitudes are considered:

- Case 1: Passive (i.e., no power consumption is considered), the *Z* axis of the spacecraft being aligned with the Earth magnetic field. Rotation rate around *Z* axis is considered at $\omega = 0.01$, 0.02 and 0.1 rad/s.
- Case 2: Active, the *Z* axis being perpendicular to the orbit's plane. Rotation rate around *Z* axis is considered at $\omega = 0.01$, 0.02 and 0.1 rad/s. This is similar to the attitude of the UPMSat-2 within its orbit (Cubas et al. 2015).
- Case 3: Active, the solar panels (2 deployable) are oriented towards the Sun during the day period of the orbit.

Details of the Subsystems of the Mission

Solar Panels and MPPT

The solar panels are made of 2 parallel-connected IXOLAR™ SM141K06L solar cells. These high efficiency (25%) monocrystalline solar cells are connected to a ST Microelectronics SPV1040 high efficiency solar battery charger with embedded MPPT. The efficiency to be used in the calculations is $\eta = 0.95$ and $\eta = 0.90$, the performance being calculated with a 1st order system and an output characteristic current to be defined based on the available literature (Porras-Hermoso et al. 2021a). Depending on the attitude case (see subsection above) different number of solar panels needs to be considered:

- Case 1 and Case 2: 4 solar panels located at $+X$, $-X$, $+Y$, and $-Y$ lateral sides of the PocketQube.
- Case 3: 3 solar panels, 2 of them deployable.

Battery

The battery selected is a commercial Li-ion battery similar to Duracell DR9714 or Sony NP-BG1, with 1240 mA·h and an output voltage ranging from 4.2 V to 3.2 V. The battery will be modeled based on the data from Li-ion batteries (discharging-charging curves) used for the simulations carried out previously by the students.

Attitude Determination and Control Subsystem (ADCS)

Only the power consumption of the ADCS needs to be considered. Students will have to review the available literature to estimate a reasonable consumption.

Voltage Regulators

The voltage regulators will have an efficiency of $\eta = 0.3$, 0.4, 0.5 and 0.6.

Power Consumption

The power consumption in the nominal mode during 1 working period, T, will be:

- Receiver (RX): 40 mW 100% of the working period.
- Transmitter (TX): 200 mW, 50% of the working period.
- OBC: 350 mW, 33% of the working period.

3 different values of T will be considered, $T = 30$ s, 5 min., and 10 min.

Operational Modes

Two modes will be analyzed:

- Nominal, which is described above.
- Emergency. TX and OBC consumptions are reduced to 8% and 1% of the working period. This emergency mode is activated in three different scenarios.
  - It is activated at 3.5 V battery voltage and deactivated at 3.7 V battery voltage.
  - It is activated at 3.0 V battery voltage and deactivated at 3.2 V battery voltage.
  - It is activated at 2.7 V battery voltage and deactivated at 2.9 V battery voltage.

Academic Skills Developed

This challenge is intended to help students to be able to acquire certain competencies and skills. First, the students must organize themselves as groups, assign tasks to each other, and establish processes of analysis of the results that impose new tasks. And thus establish an iterative work process that leads to an acceptable solution.

Also, students must decide whether the available (or starting) information is good or complete enough. If the information is not good enough, either academic sources or a reasonable extrapolation of the results of other projects and studies carried out in the master's program should be used.

Once an acceptable solution has been achieved, the students must write up the work done in a report. In itself, a report is a summary of the work done and an exercise in organizing and transmitting information. Thus, students should pay attention to:

- The writing of the text and the appropriate formats (e.g., variables in italics, use of the International System of Units...).
- Proper writing of equations and their numbering.
- The appropriate use of figures and graphs. In the case of the latter, care must be taken in the choice of scales and the use of dimensionless variables.
- Use of tables in combination with the information displayed in the graphs.

Conclusions

This article explains the way in which the EU2Space Challenge has been integrated into the academic program of the MUSE master's degree at UPM.

Challenges and competitions for students are a regular resource that has been used in the MUSE master to create exciting projects for students. However, the EU2Space challenge starts from an unusual premise in the case of space projects: it allows condensing an entire space project, from design to operation, in a period compatible with the duration of a master's degree. This is due to the use of a new type of satellite standard, the PocketQubes, with an unusually reduced scale and simplicity. And, also quite important, a very small budget.

Some of the teachers of the master have decided to explore the opportunities offered by this standard, integrating the challenge within the PBL approach of the master. The main challenge has been to adapt the requirements imposed by the EU2space challenge to the MUSE academic program. In this sense, MUSE professors have made a great effort to modify the projects that were usually carried out in their subjects, to focus on a whole satellite project that cuts across a high number of MUSE subjects. The adaptation has been a success, so the students have been able to follow up and continue the challenge within the workload of the master itself.

Although the activity is not over yet, the results so far look promising.

- It has been possible to find a sequence of subject projects with a theme and complexity appropriate to the evolution of the project.
- The students have successfully passed phase 1 of the challenge.
- Student motivation is high, as are their work levels.

For the next academic year, it is expected to verify if the satellite can be successfully launched and operated. The total costs of the project will be analyzed, as well as the feasibility/convenience of implementing the development of a PocketQube for each academic promotion as a regular activity within the master's program.

Acknowledgments

Authors are indebted to all students of the Master in Space Systems (MUSE) of *Universidad Politécnica de Madrid* (UPM) for their contributions and their motivation in the application of concepts of Concurrent Engineering (CE) approach. Authors are also truly grateful for the support of the IDR/UPM staff during the development of this work. This work is performed in the context of the IDR/UPM educational innovation group INNAERO (educational INNovation group in AEROspace engineering).

Special thanks to the ESA Academy for their help and guidance during the design sessions of the different ESA Challenge editions.

Authors are also grateful to UARX Space, Hydra Space, and AMSAT EA as the EU2Space Challenge managers.

Finally, the UPMQube project by MUSE students was partially supported by the project 478 Y2020/NMT-6427 OAPES from the program "*Sinérgicos 2020*" from Comunidad de Madrid (Spain).

References

Brodeur DR, Young PW, Blair KB (2002) Problem based learning in aerospace engineering education. In *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition, Session 2202*.

Cubas J, Farrahi A, Pindado S (2015) Magnetic attitude control for satellites in polar or sun-synchronous orbits. Journal of Guidance, Control and Dynamics 38(10): 1947–1958.

Cubas J, Pindado S, Roibás-Millán E, Pérez-Álvarez J, Sanz-Andrés Á, Franchini S, et al. (2022) An example of space engineering education in spain: a master in space based on project-based learning (PBL). In *4th Symposium on Space Educational Activities*. Barcelona.

Monteiro JB, Guerman A (2020) Nanostar, a collaborative approach to nanosatellite education. Advances in the Astronautical Sciences 173(AAS 20–226): 289–296.

Nanostar (2021a) *NANOSTAR's repository*. Available at: https://gitlab.isae-supaero.fr/nanostar.

Nanostar (2021b) *NANOSTAR's documentation*. Available at: https://nanostar-project.

gitlab.io/main/.

Pindado S, Roibas E, Cubas J, Sorribes-Palmer F, Sanz-Andrés A, Franchini S, et al. (2016) MUSE. Master in Space Systems at Universidad Politécnica de Madrid (UPM). In *ATINER'S Conference Paper Series*, No: ENGEDU2016-1953.

Pindado S, Roibas-Millan E, Garcia A, Perez-Grande I, Perez-Alvarez J (2017) The UPMSat-2 satellite : an academic project within aerospace engineering education. In *ATINER's Conference Paper Series*.

Pindado S, Cubas J, Roibás-Millán E, Sorribes-Palmer F (2018) Project-based learning applied to spacecraft power systems: a long-term engineering and educational program at UPM University. *CEAS Space Journal* 10(Mar): 307–323.

Pindado S, Cubas J, Roibás-Millán E, Pérez-Álvarez J, Sanz-Andrés Á, Perez-Grande I, et al. (2021a) Small satellite design at the UPM Master in Space Systems (MUSE). In *35th Annual Small Satellite Conference*. Logan (Utah, EEUU).

Pindado S, Roibás-Millán E, Cubas J, Álvarez JM, Alfonso-Corcuera D, Gomez-San-Juan AM (2021b) On the performance of solar cells/panels and Li-ion batteries: simplified models developed at the IDR/UPM Institute. *IEEE Transactions on Industry Applications* 57(4): 3969–3977.

Pindado Carrion S, Roibás-Millán E, Cubas Cano J, García A, Sanz Andres AP, Franchini S, et al. (2017) *The UPMSat-2 satellite: an academic project within aerospace engineering education*. In ATINER'S Conference Paper Series, No: ENGEDU2017-2333.

Porras-Hermoso A, Cobo-Lopez B, Cubas J, Pindado S (2021a) Simple solar panels/ battery modeling for spacecraft power distribution systems. *Acta Astronaut* 179(Feb): 345–358.

Porras-hermoso A, Alfonso-corcuera D, Piqueras J, Roibás-millán E, Cubas J, Pérez-álvarez J, et al. (2021b) Design, ground testing and on-orbit performance of a sun sensor based on cots photodiodes for the upmsat-2 satellite. *Sensors* 21(14): 4905.

Rodríguez-Rojo E, Cubas J, Roibás-Millán E, Pindado S, Universitario I, Ignacio DM, et al. (2019a) On the UPMSat-2 attitude, control and determination subsystem's design. In *8th European Conference for Aeronautics and Space Sciences (EUCASS).*

Rodríguez-Rojo E, Pindado S, Cubas J, Piqueras-Carreño J (2019b) UPMSat-2 ACDS magnetic sensors test campaign. Measurement 131(Jan): 534–545.

Roibás-Millán E, Sorribes-Palmer F, Chimenno-Manguán M (2018a) The MEOW lunar project for education and science based on Concurrent Engineering approach. *Acta Astronaut* 148(Jul): 111–120.

Roibás-Millán E, Sorribes-Palmer F, Cubas J, Pindado S, Chimeno-Manguán M, Alonso G, et al. (2018b) Implementation of concurrent engineering approach in MUSE (Master in Space Systems) Master's degree in space engineering. In *ATINER'S Conference Paper Series*, No: ENGEDU2018-2537.

Sanz-Andrés A, Meseguer J (2006) Three decades of space activities at IDR/UPM. In *Fortieth History Symposium of the International Academy of Astronautics*. Valencia, Spain.

Sanz-Andrés A, Meseguer J, Perales JM, Santiago-Prowald J (2003) A small platform for astrophysical research based on the UPM-SAT 1 satellite of the Universidad Politécnica de Madrid. *Advances in Space Research* 31(2): 375–380.

UARX Space SL (n.d.) *Europe to space*. Available at: https://www.eu2space.com/.

Yost B, Weston S, Benavides G, Krage F, Hines J, Mauro S, et al. (2021) *State-of-the-art small spacecraft technology*. NASA Tech. Rep. NASA/TP-2020-5008734.

Zamorano J, Garrido J, Cubas J, Alonso A, de la Puente JA (2017) *The design and implementation of the UPMSAT-2 attitude control system*. IFAC-PapersOnLine 50. Available at: https://doi.org/10.1016/j.ifacol.2017.08.1607.