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Implementation of Concurrent Engineering Approach in MUSE (Master in Space Systems) Master's Degree in Space Engineering

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Abstract

In September 2017, the second-year students of the Master's Degree in Space Systems (MUSE) from *Universidad Politécnica de Madrid* (UPM) had the opportunity to participate in the 1st ESA Academy Concurrent Engineering Challenge, organized by ESA Academy's Training and Learning Centre, together with *Politecnico Di Torino* (Italy), University of Strathclyde (United Kingdom) and ESA Academy (Belgium) students. The four-day challenge was focused on thePhase-0 design of a space mission fully developed based on a Concurrent Engineering (CE) approach. The UPM team design was conducted within the Concurrent Design Facility (CDF) of the *Instituto Universitariode Microgravedad 'Ignacio Da Riva'* (IDR/UPM), located in Madrid, by the supervision of two UPM Professors acting as System Engineers of the sessions. From the academic point of view, this experience was integrated within MUSE's program as Study Case II. MUSE is promoted, implemented and fully organized by IDR/UPM, and it is based on Project Based Learning, taking advantage of the wide expertise of IDR/UPM on space research and technology. The educational program is focused on practical work within real space engineering projects of IDR/UPM and by collaboration with several space scientific institutions. The aim of this work is to present the academic possibilities of the IDR/UPM CDF. Besides, the ESA Challenge structure and the mission developed by MUSE students are also described, as well as the future challenges proposed to integrate CE within MUSE's educational program.

Keywords: Concurrent Design Facility, Concurrent Engineering, Mission Design, Project-Based Learning, Space Technology.
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Introduction

Since July 2011, IDR/UPM (*Instituto Universitariode Microgravedad 'Ignacio Da Riva'*) of *Universidad Politécnica de Madrid* (UPM), has an institutional agreement with the European Space Agency (ESA) to develop a Concurrent Design Facility (CDF) for educational purposes.

This facility has been developed to promote the design of systems and missions through Concurrent Engineering (CE) approach. The purpose is to accommodate various discipline engineers (usually one per discipline) in the same room, so that the design process and information exchange can be performed face-to-face and in real time. Therefore, the specialists' common effort is concentrated on the truly interdisciplinary aspects of the design and this process is optimized by means of real-time collaboration and data sharing between disciplines.

The Concurrent Engineering concept dates from 1995 and it is based on two key elements, the first one is the idea of tasks parallelization (or performing tasks concurrently) and the second one is to take into consideration all the elements of a product life-cycle from the beginning of the design phase (Casani and Metzger, 1995). The main idea is to increase productivity and product quality, providing a collaborative, co-operative, collective and simultaneous engineering working environment. Besides, this approach tends to replace the time-consuming linear process of serial engineering.

Since its approval by the Spanish National Agency for Quality Accreditation (ANECA) on May 2014, the Master in Space Systems (MUSE) from UPM University is organized and conducted by IDR/UPM. The solid foundations of IDR/UPM Institute on space engineering, acquired through a host of relevant projects carried out in the last decades, have led to focus the MUSE students training methodology using a Project Based Learning (PBL) approach (Barthol et al., 2011; Neefs et al., 2015; Patel et al., 2017; Pérez-Grande et al., 2009; Thomas et al., 1998).

The development of the CDF motivated the MUSE professors to implement its use for educational purposes, thus introducing the students CE concepts.

The main goal is to train the students in the character of today's engineering process whereby the design optimization, materials choice, analysis, simulations, prototyping, etc., must be performed simultaneously. Therefore, changes and information derived from any of the specialist's activities is directly accessible to everyone in the whole process. By implementing this agile working methodology, MUSE students are trained to be more generalists instead of being only specialists in a single area (such as design, finite element analysis, manufacturing, etc.), having good understanding of each aspect of the design, materials, simulation and manufacturing processes.

Within this framework, in September 2017, students and professors of MUSE had the opportunity to participate in the *1st ESA Academy Concurrent Engineering Challenge* organized by European Space Agency (ESA), as an effort to promote the use and development of CDFs in European institutions and to train future engineers in the Concurrent Engineering methodology.

In the following subsections, the Master on Space Systems is briefly described, emphasizing on the PBL used approach and the Concurrent Engineering concept. In addition, the application of Concurrent Engineering in MUSE within the PBL approach is described, as well as some examples of its particular implementation on the IDR/UPM CDF. The aforementioned *1st ESA Academy Concurrent Engineering Challenge* is also overviewed, placing emphasis on the mission developed by MUSE students and, to conclude, the future challenges proposed for a more efficient application of CE approach in the MUSE educational program are described.

Overview of the Master in Space Systems (MUSE)

The Master's degree in Space Systems (MUSE) is composed of a second-year course (120 ECTS) designed to provide a practical and continually updated approach to space technology and research activities in space sciences (Pindado et al., 2018, 2016; Pindado Carrion et al., 2017).

The master course is classified into theoretical and practical lessons related with space technologies, classified into five different groups:

- Advanced Mathematics
- Space Projects Definition
- System Engineering
- Spacecraft Subsystems
- Case Studies and Final Project

In addition to the academic load, the students of MUSE have been involved (since the first group of graduates in 2015) in some of the projects of IDR/UPM Institute in space technologies and systems. The participation of students in real projects allows a close collaboration between them and professors and research staff, providing the opportunity to share the experience acquired through real-life projects.

The advantages of this methodology are clear: students acquire hands-on experience through participation in real space projects, they become strongly motivated since they have an immediate feedback on the benefits of their work and their background is highly improved.

Nevertheless, the harmonization of an educational degree with the development of a space project has been the most important goal for the professors from the IDR/UPM Institute. A high quality work must be maintained but it is not completely performed by experienced professionals, so the key point is to maintain a perfect guidance and monitoring of the students work.

The Multidisciplinary and Project Based Learning Approach

The key aspect of the Master in Space Systems (MUSE) is the use of a Project Based Learning (PBL) approach, making use of the experience accumulated by the IDR/UPM staff in space sciences and technologies during the past fifty years. PBL main goal is to provide students with the opportunity to apply their knowledge, not just acquire it, focusing on formulation as well as solving of real-world engineering problems (Brodeur et al., 2002).

Through this methodology, students are forced to confront real problems, encouraging them to look for solutions through joint collaboration and teamwork.

The use of a PBL approach results in a high motivation of students, which have caused minimal dropout rates since the master implementation.

In addition, PBL has revealed as the best way to combine the needs from space industry and the academic requirements, producing links for the students future professional careers. The immediate impact of this university-industry collaboration is the fast insertion of graduates into the labor market.

As is required in space sciences and technology, the complex nature of the space missions implies that each discipline is related to the rest with a high degree of coupling, resulting in a multidisciplinary working environment. Therefore, in an engineering degree, the training must be focused on promoting the multidisciplinary aspects. Indeed, Bordogna et al. (1993) suggest that ‘the intellectual components of engineering should be connected holistically to avoid the so-called *fractionated knowledge* that is not relevant in the real world’.

However, the general practice is to stratify senior design courses by discipline, which prevents a collaborative exchange of expertise, knowledge and experience across domains.

Within MUSE, IDR/UPM professors have implemented a multidisciplinary teaching process, providing students an opportunity to integrate theory with practice within their knowledge domain and working towards a cooperatively constructed design project.

Therefore, students are afforded the opportunity to experience and demonstrate that engineering graduates can function on multidisciplinary teams, applying their knowledge of mathematics, science and engineering to identify, formulate and solve the complex challenges of today’s engineering practice.

This methodology also enables students to communicate effectively, understand the ethical responsibility and use the techniques, skills and modern engineering tools necessary for engineering practice in the real world.

In Table 1, the five groups of subjects included in the Master of Space Systems (MUSE) program are classified according to the type of learning employed.

As it is shown, over 50% of the total academic load of the master is focused on a multidisciplinary approach and based on PBL.

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**

Concurrent Engineering within Project Based Learning (PBL) Approach

Within the Project Based Learning (PBL) approach, learning becomes an act of discovery as students examine the problem, research its background, analyze possible solutions, develop a proposal and produce a final result. When the topic to be studied is related with the design of a space mission, the multidisciplinary nature of this discipline is even more evident.

Usually, for space mission design, a team of system engineers and domain specialists apply their knowledge and experience to identify a feasible solution that fulfills the mission main requirements. It is the multidisciplinary character of the space mission design.

In addition, during the first phases, a multiple of possible design solutions with different parametric settings need to be simulated and evaluated to achieve an objective design decision. The traditional activities and studies are usually implemented sequentially and independently. This consequently results in excessive time and cost due to the isolated activities.

Some effort has been applied on exploiting methods in the field of multidisciplinary design optimization or to reduce the complexity of the possible mission scenarios but during last two decades, the effort is focused on the development of the concept of Concurrent Engineering (CE) (Budianto and Olds, 2000; Salotti, 2004).

The motivation to introduce CE in the MUSE educational model is that allows the students to be up to date with the latest design trends and to enhance the agility, timeliness and competitiveness of future engineers to rapidly realize systems or products in today's changing market.

By combining the PBL approach with CE approach, students are taught to abandon the obsolete concept that both products and systems realization consist of sequential steps of design, material selection, analysis and manufacturing, with each step being handled by experts or specialists having only sequential and marginal interface with each other. In addition, the students will be taught that to be competitive, as the product realization needs to be an agile concurrent process.

Concurrent Engineering (CE) at IDR/UPM Institute

The idea of Concurrent Engineering (CE) has been successfully applied on IDR/UPM Institute since the development of its Concurrent Design Facility (CDF) (Figure 1).

The IDR/UPM CDF is located in the Montegancedo campus (Madrid, Spain) together with the rest of facilities of IDR/UPM for space systems manufacturing, integration and testing (manufacturing plants, clean room, vacuum thermal chamber, vibration room, etc.).

This CDF, continually under development since its opening, is based on European Space Agency (ESA) CDF design guidelines and recommendations (ESA, 2011). To fulfill the requirements, a software infrastructure is needed including tools for the generation of the different models, integration between them to propagate data in real time, a documentation system and storage capability.

To this end, the developed facility consists of twelve workstations for space mission subsystems specialists, a system engineer or session conductor workstation, an audiovisual distribution system, a server, a videoconference system and four shared screens.

Figure 1. *Concurrent Design Facility (CDF) of the IDR/UPM Institute*

The CDF software is based on a database system that includes an application server and end-user applications, the Open Concurrent Design Server (OCDS) (based on ECSS-E-TM-10-25S, 2011). To interact with the database an add-in on top of Microsoft Excel© is used, the Con CORDE (Concurrent Concepts, Options, Requirements and Design Editor).

In addition, several calculation models are needed for the specialist to calculate and simulate their respective subsystem variables. Those calculation modules could be as complex as needed depending on the mission requirements and the order in which each discipline is solved, thus dictating which variables are of a dependent nature and defining the causality criteria employed. For example, structure parameters (shape, material, stiffeners, etc.) may depend on launcher selection, or power subsystem size may depend on payload power consumption requirements, while is the specialist himself who decide the type of attitude control elements to be selected to fulfill the mission requirements, being this selection independent on the rest of subsystems variables.

Application of Concurrent Engineering (CE) in the Master in Space Systems (MUSE)

Taking advantage of the CDF development at IDR/UPM and following PBL approach, students of the Master in Space Systems (MUSE) are experiencing the opportunity to deal with the concept of Concurrent Engineering in two ways:

I. Students have the chance to participate in the CDF modules development and implementation as part of their Study Cases or Final Projects (see Table 1).
II. Students have the opportunity to participate in full mission design sessions as part of their academic load (framed within the Space Engineering group of subjects, thus increasing the academic load percentage dedicated to multidisciplinary and PBL activities shown in Table 1).

Regarding the first point (I), and since the creation of the CDF, several projects related to the development of tools and utilities for space mission design have been carried out by the students of the Master in Space Systems (MUSE) as Case Study I, II, or III, or Final Degree Project, under the direction of IDR/UPM professors. Among them, the following ones could be mentioned:

- Creation of subsystem modules (power, attitude determination and control, communications, thermal, structures, propulsion, orbital design, etc). Several projects have been developed in this line, using dedicated software for parameters and variables calculation. Between them, the following works could be pointed out:
  - Power subsystem module. Several modules has been developed and improved by second-year MUSE students. Using C++ software and Matlab©, all the elements of the power subsystem can be selected to fulfill the mission requirements. An analysis of equivalent circuit models of solar panels can be performed, taking into account different temperatures and solar radiation angles to the panel surface to simulate their behavior. The solar cells, support panels materials and the type of batteries employed can be selected from a database, always finding the better solution for each mission. The power distribution system and the converters are also calculated in terms of mass and power consumption.
  - Thermal subsystem. Using Microsoft Excel© format, a complete module for thermal subsystem sizing was performed by a second-

year MUSE student. Hot and cold stationary and transient cases are studied as a function of the selected orbit. Different types of active and passive thermal control elements can be used, as heaters, multi-layer insulations, radiators, paint types or surface treatments, depending on the mission requirements. The input variables to the thermal subsystem are strongly influenced by the rest of subsystem variables so the options to be selected must be as flexible as possible in order to find a feasible thermal solution.

  - Structures module. Using Microsoft Excel© as interface to exchange input and output variables, the structure design can be performed using 3D CAD (Computer-Aided Design) software. The spacecraft or system shape can be selected as well as the material properties (from a database or introduced by the user), the loads and stresses are estimated to evaluate the need for stiffeners, and the margins can be calculated. In addition, the inertia moments and center of gravity are calculated and the first eigen-frequencies are estimated using FE models so Microsoft Excel© is also used as interface with NASTRAN©.
  - Orbital design. Satellite Toolkit (STK), General Mission Analysis Tool (GMAT) and Microsoft Excel© sheets have been developed by the students to generate a model to estimate and optimize spacecraft trajectories.
  - Attitude control system. Although it is not implemented yet in the CDF system, MUSE students have been developing tools to study and simulate the attitude of space missions. The environmental simulator and visualization tool of Satellite Toolkit (STK) software has been combined with the computational capacity of Matlab© using a custom interface, in order to study the attitude control system of the UPMSat-2, a micro-satellite under development by IDR/UPM staff (Pindado Carrion et al., 2017). A simplified version of this tool will be used to improve the attitude control subsystem module.

- Development of an information exchange system. Some second-year MUSE students have focused their works on the development of a system to easily manage and exchange the parameters and variables between the different subsystem modules. The effective management and exchange of parameters is the key point of a functional CDF, since is the communication path between different specialists and disciplines. Therefore, a successful design is largely influenced by the way those parameters are shared, modified, actualized and managed. The developed system is composed by a hierarchical system in which the different parameters are organized by owner disciplines (with writing/modifying permissions) and dependent disciplines (with reading permission).

Regarding the second point (II), first and second-year MUSE students have had the opportunity to participate in full mission design campaigns, being the following ones the most relevant:

- Phase-A design for UNION Lian-Hémicro satellite. UNION Lian-Hé is a 50 kg-class, university satellite, which is being developed by cooperation between IDR/UPM Institute and the School of Astronaut is in Beihang University (SA/BUAA, Beihang, China). The project shares the general, educational, technological and scientific goals of both institutions. Moreover, it will supply an open, hand-on practice-training platform for the young aerospace engineers through innovative international cooperation.
  The design philosophy along the project is focus emphasizing mission analysis and top-level design to optimize the overall program. A reasonable selection of Commercial-Off-The-Shell (COTS) components is carried out to ensure reliability while reducing costs. To meet these requirements the project must be kept between limited boundaries, assuming minimum technological risks.
  As the design is performed by cooperation with a China university, the interaction between specialists of both institutions is a hard task (because of the distance between institutions and the language barrier). In this case, the use of Concurrent Engineering is even more important to reduce risks and costs in the mission development phase. MUSE students performed the mission design using the CDF on September 2016, with the guidance and support of IDR/UPM system engineers (García et al., 2016). The design process was composed of three design iterations, being the last a success in terms of mission requirements fulfillment.
  The final design has been used for the project Phase-B. Besides, a minimal amount of changes have been needed with regard to the final iteration performed by students.
- 1st *ESA Academy Concurrent Engineering Challenge.* This challenge was organized by ESA Education Office, in collaboration with ESA's Systems and Concurrent Engineering Sections. The challenge featured groups of 15-25 students, each one supervised by two system engineering in different CDFs within ESA Member and Associate State universities and an additional group in ESA Academy's Training and Learning Centre. ESA proposed a specific mission to design within four days.
  Students in each group were classified into small teams of two or three to cover the main space mission disciplines (i.e., structures and configuration, power, orbit analysis, thermal, attitude and orbit control, communication and data handling.). Students within each small team had to create a subsystem concept in order to later achieve the mission parameters using the CE approach.
  The challenge itself is not a competition but an opportunity to share the progress of each day, raise any difficulties they are facing and receive helpful input from the other participants. At the end of the challenge each

group presented their final design.

The 1st ESA Academy Concurrent Engineering Challenge

As aforementioned, in March 2017, ESA Academy called for the 1st *ESA Academy Concurrent Engineering Challenge* as an extension of ESA concurrent engineering culture to its educational programs. The challenge was held between September 12th and 15th with the objective of designing a satellite by European students simultaneously in different CDFs.

European students of four different institutions were invited to participate in the challenge: students at 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), students of University of Strathclyde (United Kingdom), and MUSE students from *Universidad Politécnica de Madrid* (Spain). In Figure 2, a picture of the second-year MUSE students in IDR/UPM CDF is shown.

Figure 2. *Second-year MUSE Students in the IDR/UPM Institute Concurrent Design Facility (CDF) during the 1st ESA Academy Concurrent Engineering Challenge*

The mission was intended to be fully developed using a Concurrent Engineering approach emphasizing the influence between disciplines, which allows the students to keep the whole system in mind being able to achieve higher design cohesion.

To perform the challenge on equal terms all the basic subsystem modules were provided by ESA. In addition, all the institutions were free to use any additional tool available in their respective CDFs.

The Challenge Proposed Mission

The main objective of the proposed mission is to identify feasible areas for a future human base in the Moon Surface. To this end, the primary objective is to evaluate the presence of water in the surface of the Moon. Therefore, the mission shall make pictures of the Moon South Pole areas with high-expected water/ice content and with a resolution of 10 m/pixel.

To evaluate the feasibility of a future human base, two secondary objectives are stated: first, the mission shall observe the lunar radiation due to the relevant importance of the radiation environment in a long term stay, both on lunar surface as in lunar orbit. Second, the mission shall evaluate the micro-meteorite environment because it is a key point to guarantee the survival of a long term orbiter (e.g. relay satellite, escape shuttle, etc.).

The key point of the challenge is to design a small low-cost mission, taking into account latest Cube-sat developments. It should be assumed that the mission would be managed/procured by ESA and that the project Phase-A does not start before 1 January 2019 so, assuming four years of development, it gives a launch in 2023. In summary, the mission requirements are the followings:

1. The mission shall make pictures of Moon South Pole areas with high-expected water/ice content, with a resolution of 10 m/pixel.
2. The mission shall observe the lunar radiation and micro-meteorite environment.
3. The mission shall consist of a single satellite or a single plane constellation.
4. The mission shall stay in Lunar orbit for 2 years.
5. The mission shall be launched using an Ariane shared GTO (Geostationary Transfer Orbit).
6. The mission shall be compatible with any launch date between years 2023 and 2025.
7. The total combined mass of the whole system shall be 300 kg.
8. The mission should use COTS (Commercial-Off-The-Shell) components.
9. The mission shall have and end of life disposal maneuver.
10. The mission shall use direct to earth communication.

It should be emphasized that the participation in this challenge represents an opportunity for university students to contribute to the scientific knowledge of the Moon and allows to fully prepare a well-qualified workforce for future ESA missions, in particular those planned by the exploration and science programs in the next decades.

The MUSE Students Mission Proposal: The MEOW (Moon Explorer and Observer of Water/Ice) Spacecraft

The mission designed by MUSE students during the 4-days session, is classified into five different phases ranging from the deployment of the satellite in the GTO orbit to the disposal maneuver (Roibás-Millán et al., 2018). The different phases can be summarized as follows:

- Mission phase 1: Comprises the deployment of the spacecraft into GTO from the Arianne V upper stage, the attainment of a stabilized attitude and the conduct of checkout activities (ground system checkout and functional tests during ground station visibility periods). The estimated duration is about 1 week.
- Mission phase 2: This phase, with duration of 3 months, comprises the transfer phase from GTO to Moon orbit, to place the spacecraft in a stable lunar polar orbit with a perilune altitude of 100 km. To be compatible with any launch date and to achieve the selected orbit, a Weak Stability Boundary (WSB) Low-Energy transfer trajectory from GTO to the Moon via Sun-Earth was selected.
- Mission phase 3: During 10 months, the lunar imaging phase is performed. A continue image of the lunar surface is downlinked in each orbit.
- Mission phase 4: After the 10 month imaging phase, the main objective of the scientific mission is considered achieved and the rest of the time is dedicated to the study of radiation environment and micro-meteorites detection.
- Mission phase 5: The end-of-life maneuver is performed. To this end, a final Delta-V is applied to deorbit the satellite in the Moon surface outside of the survey region.

To fulfill the science mission requirements, the following payloads onboard the spacecraft were selected:

- Terrain mapping camera: It is a stereoscopic instrument in panchromatic band for topographic mapping with high spatial and altitude resolution. The South Pole covered area is a circular surface of 600 km of diameter and the observation time is about 340 s. Therefore, 47 orbits are needed to complete the total South Pole surface mapping. The ground resolution at the orbit perigee is 5 m/pixel, for a 100 km altitude. When the satellite enters/exits the survey region (with an altitude of 260 km) the resolution is 9.2 m/pixel, achieving the mission requirements.
- Spectrometer: For observation and detection of water and ice in the Moon surface.
- Micro-meteorites detector: This payload measures the electrical charges generated by the impact of small masses on a gold surface.
- Radiation detector: Composed of three detectors, one for the first energy range (200 keV to 100 MeV, for low linear energy transfer), and two for the second energy range (2 MeV to 1 GeV, for high linear energy transfer).

The primary structure is a semi-monocoque octagonal prism of 0.9 m high and 0.64 m of apothem, constructed from carbon fiber LTM45E, and reinforced with eight stringers providing the stiffness needed to withstand loads during launch, as well as positive buckling and static loads margins. The total wet mass of the spacecraft (including margin of 20%) is 262 kg so the total mass requirement for the launch is fulfilled. A picture of the MEOW spacecraft is shown in Figure 3.

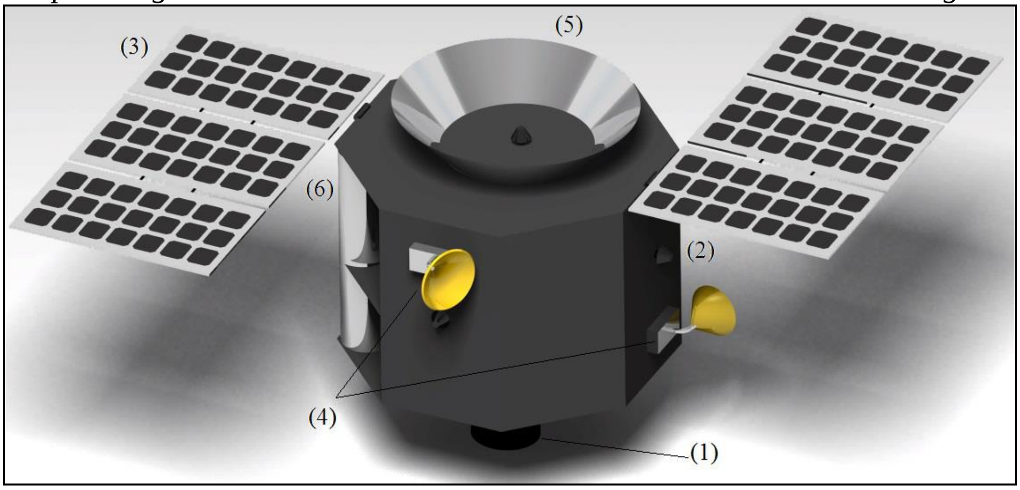
The propulsion system consists of a commercial bi-propellant rocket engine, responsible for the main propulsion of the satellite during mission phase 2 (the transfer phase) and mission phase 5 (end-of-life).

To properly photograph the Moon South Pole, a 3-axis stabilized system was selected. The main objective was to reach a nadir stabilized pointing during each spacecraft pass over the South Pole so a zero-momentum system composed of 4 reaction wheels (one of them for redundancy) was selected. For orbit maintenance and reaction wheels desaturation, 9 thrusters were positioned in the external surface to achieve the 3-axis control.

The power plant subsystem consisted of two deployable and steerable solar panels and a lithium-ion battery of 400 Wh, able to provide the required electrical power during the Moon eclipse of maximum duration. During the second-year mission, on 5th May 2023, an Earth eclipse event of about the 78% of the orbital period will take place. During this event, the satellite is required to enter in latency mode (the OBC is switched off in order to allow the batteries to be charged) to ensure the survival of the mission.

The OBDH subsystem, based on COTS elements, is composed of an onboard computer or microprocessor, the data handling system and the analog-to-digital converters (ADC).

Figure 3. *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*



Finally, for earth communication, a double system was selected: a S-band antennae system (with 5 S-band antennae distributed around the spacecraft structure) for GTO orbit and WBS transfer; and a 2 X-band steerable antennae system for Moon orbit. The main ground station and mission control will be located in Madrid, Spain (40.42ºN, 3.79ºW) although some other ground station options could be required to support the mission.

Future Challenges to Apply Concurrent Engineering (CE) in MUSE Academic Program

Since the early days of the IDR/UPM CDF, MUSE students have conducted the development of tools and utilities for space mission design under the direction of professors and IDR/UPM staff. At present, some first and second-year students are building a set of models of the main spacecraft subsystems to study mission beyond Earth.

In addition, some full design sessions have been conducted in the last two years, targeted at second-year MUSE students because they are considered to have all the necessary knowledge and expertise to make the most of them.

The main goal of the last year is to implement the idea of Concurrent Engineering (CE) from the beginning of the master courses. This clearly presents practical problems due to the lack of knowledge of first-year MUSE students in some of the required disciplines. For example, up to the second-year students are not acquainted with methods for attitude determination and control, or concepts related to satellite communication systems.

In order to make easier for students to achieve the proper level of knowledge and experience, a frame of cooperation is being established between the students from the first-year, who are new to the CE concept, and second-year students, that have gathered a significant level of experience through the Case Studies and CDF design sessions. This cooperation enables the comprehensive and resource-effective use of the CDF and ensures the success in the mission design studies.

With this purpose, on February 2018, a CDF design session was conducted headed by an IDR/UPM system engineer and three second-year MUSE students. During this session, first-year students had the opportunity to become familiar with the CDF available tools and to fully develop a Phase-0 space mission guided by their second-year classmates.

The proposed mission was based on an IDR/UPM Institute future project, so the purpose of the study was to evaluate the feasibility of the solutions proposed by IDR/UPM staff.

The Phase-0 Mission Design of a RF-band Calibration Pattern for an Orbiting Telescope

The mission itself consists of an auxiliary Cube-sat located in the same dawn-to-dusk orbit than the main spacecraft, an orbiting telescope, at a certain distance from it. A set of RF horns onboard the Cube-sat are used to calibrate the telescope and the distance between the two spacecraft must be maintained within the range 100-200 meters.

As result of the training session, the students’ motivation and their vision of the CDF possibilities increased significantly, to the extent that many of them have chosen to perform their Study Cases on CDF modules and tools development. In addition, the mission design was considered a huge success, despite the short experience of the first-year students.

Conclusions

The academic possibilities of applying Concurrent Engineering (CE) and the use of Concurrent Design Facilities (CDF's) in Master studies have been proved through its implementation in the Master of Space Systems (MUSE) of the IDR/UPM Institute. The method has proven highly effective in terms of motivation and academic productivity in MUSE students, as it can be seen from the academic results and satisfaction surveys carried out by MUSE professors.

MUSE students had the opportunity to participate in the 1st *ESA Academy Concurrent Engineering Challenge*. This experience had the purpose of showing the students that by means of CE a faster pace of design refinement can be achieved. By considering simultaneously the design changes in each subsystem allows to increase the time efficiency for the mission design, compared to the amount of time needed for a sequential design process, i.e. iterating sequentially each sub-system with the input of the whole system previous iteration.

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