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Nanosatellite Development Methodology and Preliminary Design Guides for the NANOSTAR Project

Daniel Lubián-Arenillas⋆†*, José Miguel Álvarez*⋆*, Juan Bermejo*⋆*, Sergio García*⋆*,*
Javier Cubas⋆ *and Elena Roibás-Millán*⋆
⋆*Research Institute for Microgravity Ignacio Da Riva, Technical University of Madrid*
Plaza Cardenal Cisneros, 3, 28040 Madrid, Spain
`d.lubian@alumnos.upm.es`†
`{jm.alvarez,juan.bermejo,sergio.garcia,j.cubas,elena.roibas}@upm.es`
†Corresponding author

Abstract
The objective of the NANOSTAR project is to promote the development of small satellites in South-Western Europe by creating collaborations between the partners, developing new tools and facilities and testing them through student challenges. In this paper is presented the nanosatellite development methodology and the collaboration methodology for the first phase of the student challenges. The documentation for the students was prepared based on a survey on nanosatellite development methodologies, and is divided in preliminary design guides, management methodologies and overviews of ECSS standards, collaborative tools and concurrent engineering. Finally, some conclusions are drawn from the Student Challenge.

1. The NANOSTAR project

The objective of the NANOSTAR project is to create “a collaborative platform to provide a relevant training on nanosat technology through Student Challenges” [1]. This project is funded by the Interreg Sudoe Programme through the European Regional Development Fun (ERDF), and has a planned duration of 30 months (starting April 2018) and a total budget of 2 million euros. The logo is shown in fig. 1.

Figure 1: Logo of the NANOSTAR project, with the logo of the Interreg Sudoe Programme.

The idea is to support the development of nanosatellite programmes, and eventually companies, in south-western Europe (Portugal, Spain and France). In contrast to the north of Europe, where several countries have invested in the nanosatellite sector, creating a commercial offer that has become very well positioned in the market. However, Southern Europe has only 14% of the projects in the European nanosatellite sector and very reduced number of companies created in this field, despite its strong influence in the space sector. NANOSTAR is a European project to support the training and development of student nanosatellites in the south west of Europe. Therefore, this project involves seven universities, two aerospace clusters and three ESA’s Business Incubation Centres (ESA-BIC) as associates from this region. The partners of this consortium are:

- Universities:
  - Institut Polytechnique de Bordeaux, Equipe Géoressources et Environnement (INP)

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  - Institut Supérieur de l'Aéronautique et de l'Espace (ISAE)
  - Université de Montpellier (UM)
  - Universidad Politécnica de Madrid (UPM), Instituto Universitario de Microgravedad "Ignacio Da Riva" (IDR)
  - Universidad Carlos III de Madrid Escuela Politécnica Superior, Departamento de Ciencia e Ingeniería deMateriales e Ingeniería Química (UC3M)
  - Universidade da Beira Interior, Faculdade de Engenharia (UBI)
  - Instituto Superior Técnico (IST)
- Aerospace clusters:
  - Aerospace Valley (AV)
  - Madrid Aerospace Cluster (Madrid Plataforma Aeronáutica y del Espacio, MAC)
- ESA-BIC (associates):
  - ESA-BIC Sud France
  - ESA-BIC Portugal: Instituto Pedro Nunes – Associação para a Inovação e Desenvolvimento em Ciência e Tecnologia
  - ESA-BIC Spain (Madrid)

The project is divided in five technical tasks: creation a database of common resources, development a concurrent engineering software solution, development of a work methodology, coordination of student challenges and evaluation of the project. The three first parts allow the creation of the NANOSTAR network and setting up the collaborative platform, that will be tested during the student challenges (the forth part). Finally, the consortium will try to maintain the collaboration between the partners and work with the ESA-BIC to create new nanosatellite companies.

The student challenges are divided in two phases. Phase 1 consists on a preliminary design of a Moon-flyby CubeSat mission according to a given set of requirements. Several student teams across the consortium universities will compete for the best solution using software from the Concurrent Engineering Centre (Centre d'Ingeniérie Concurrant,CIC) at the National Centre for Space Studies (Centre National D'Études Spatiales, CNES), since concurrent engineering is part of the NANOSTAR project guidelines. The winners of this phase will act as systems engineers of Phase 2.

The detailed design, development and testing is part of Phase 2 and will be divided in several challenges. Each challenge will be tackled by at least a couple of teams from different institutions. Teams must communicate with each other to ensure consistency.

2. Review on existing methodologies for nanosatellite development

In this section, there is a review of several methodologies applied to nanosatellite development, tested or to-be-tested, found in the literature and used by the NANOSTAR consortium. There is as well an inventory of collaborative methodologies found in other industries that could be useful in projects of these characteristics.

2.1 Methodologies based on systems engineering and the ECSS standards

The European Cooperation for Space Standarization (ECSS) standards are the result of a European effort to achieve a common working process for all kind of space projects, covering every single system and process in their development. Therefore, these standards have been followed by most space projects in Europe for the last 20 years, making their proposed methodology the traditional one.

During the whole process (initial studies, design, production, testing and operation), the ECSS standards provide the number and type of documents that should be released as well as the reviews that should take place. Also, they both recommend and forbid the use of certain technologies and materials in space missions, depending on their specific application. Following these standards is usually a requirement imposed by ESA when working with them and, consequentially, with the most important companies and institutions in the European space industry. Space systems engineering defines a framework of requirements and objectives that must be fulfilled. In this approach, the design phase is usually an iterative top-down process that reaches a solution in compliance with said requirements and objectives. The systems engineer is the person that acts as the link between the different subsystems and coordinates the different aspects of the design process to ensure compliance with the solution.

According to *ECSS-M-ST-10C – Project planning and implementation* [2], a space project is divided into the following phases:

- Phase 0: Mission analysis/needs identification

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- Phase A: Feasibility
- Phase B: Preliminary Definition
- Phase C: Detailed Definition
- Phase D: Qualification and Production
- Phase E: Utilization
- Phase F: Disposal

This structure comprises and orders adequately all processes, tasks and work packages in the development of a traditional space mission. Important reviews take place at the end of each phase, i.e. to proceed with the next phase a formal review must be successfully passed. Some of these reviews are:

- Mission Design Review (MDR)
- Preliminary Requirements Review (PRR)
- Preliminary Design Review (PDR)
- Critical Design Review (CDR)
- Acceptance Review (AR)
- Launch Readiness Review (LRR)
- End-of-Life Review (ELR)

Phase 0 and A usually happen together and are involved in the detection and development of an idea and its feasibility, producing at the end the PRR. Phase B is when a more precise definition of the mission and its design is made. This means that the first specific studies are carried out and the most important decisions have been made. For the end of Phase C, the design must be frozen as well as the rest of the decisions that will happen in the future, like the Assembly, Integration and Testing (AIT) plan and the project schedule. This information is completely settled for the CDR. The assembly, integration, testing and verification are the most important tasks in Phase D, when everything is subjected to a qualification process that ends with the launch and beginning of the mission. Finally, the mission ends.

Although this thoroughness is a great advantage for traditional space missions, the associated documentation may be overwhelming for a nanosatellite team. Traditional missions often take several years before launching, since large spacecraft have an increased complexity that a nanosat mission typically does not have, mainly due to its size and the use of Commercial-Off-The-Self (COTS) components. Also, nanosatellite missions are normally composed by small teams and their pre-operational phase is usually shorter (it is not rare to be less than two years), so a significant part of the ECSS standards may be making the development more difficult rather than facilitating it.

With that in mind, some efforts have been made to tailor the ECSS standards to nanosats, concretely to their most popular version, the CubeSats. These works have tried to establish what standards are applicable (sometimes with modifications), a guideline to follow or not applicable, simplifying the compliance with these standards for this type of projects.

The Engineering branch of the ECSS standards was tailored by ESA for in-orbit demonstration CubeSats in [3]. The main key points of this document are:

- Higher risk acceptance profile, single point failures are accepted, limited redundancy.
- Extensive use of COTS elements, with flight heritage, simplifying the requirements and their testing.
- Testing is focused on system level.
- The procedures written in the system engineering documents are applicable for the verification, testing and environment processes. Most of the rest are guidelines.
- Electrical engineering is applicable in general and for photovoltaic components.
- In terms of the field of Mechanical engineering: the procedures for thermal control, materials, mechanisms (if present), liquid and electric propulsion and pressurized components are applicable, as well as structural general requirements.
- Software, control, ground system and operations documents are mostly guidelines, except for Attitude and Orbit Control System (AOCS) requirements.
- Communications general document is applicable.

There are two more promising documents[4, 5] that should give more details about the tailoring of the ECSS to CubeSat projects.

2.2 Methodology based on NASA's systems engineering approach

An adaptation of NASA's procedures for space missions was proposed by Shiotani et al. [6]. NASA project life-cycle is very similar to the one described in section 2.1 by the ECSS: the phases have approximately the same names and expected tasks.

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In this document it is suggested that in CubeSat projects whose mission is technology demonstration, some components (sensors, actuators, payload, etc.) are designed, analysed and prototyped at the same time. COTS components are also very common in these projects, so the preliminary trade study may be accelerated considering flight heritage and past experiences. This leads to Phases 0 (Pre-Phase A for the ECSS), A and B happening at the same time and being less well-defined. The authors call the combination of these three phases Phase AB, because activities are now integrated to make everything more efficient and effective. Phases C, D, E, and F follow the same structure as NASA's, so no relevant remarks for them.

Another important part in [6] is the proposal of a mission assurance procedure for CubeSats-based missions. In Phase AB, it is too early to perform any verification tests, but reviews should focus on preliminary concepts of operations, design processes and satisfying CubeSat standards.

Detailed design is finalized during Phase C, so testing, validation and verification plans must be developed in parallel to be performed in the next phases. It is important to start applying these procedures for modelling and simulation tools to increase the confidence in the design, as well as making the first metrology and functionality tests in different environments for all components, but specially COTS components, both independently and collectively (to avoid compatibility issues). This will lead to the final design decisions. Finally, any needed test beds should be acquired, or developed, and tested.

Most of the tests are carried out in Phase D, starting with component level, then sub-assemblies, subsystems and finally the whole system. Two models are proposed here: the Flight Model and the Engineering Development Unit

2.3 Methodologies based on Agile development

Agile system engineering practices are well established methodologies in software projects and being now explored and studied to be applied in complex hardware projects. These practices permit a flexible and development working environment while allowing risk uncertainties to be managed in a disciplined manner. The principles that sustain this methodology decrease the constraints of development procedures and increase the responsiveness to the sponsor of the project. Some key points are self-organizing teams and a minimum number of documents written, maximizing its content and improving them continuously.

The main idea of these methods is to break the product development into small increments and tasks instead of approaching the problem with big work packages. In each short iteration, all members of the team work in design, analysis and testing/review/quality checking, with daily quick meetings to update their progress to the rest of the team. This process is similar to the first steps in a concurrent engineering process, but in this case every member of the team works in all parts of the software, so everyone gets a global view of the product.

Another difference with concurrent engineering is that these practices are applied throughout all the product development, something feasible with small teams. Applying these ideas are also possible for student teams, since their knowledge may not be as specialised as in traditional projects and they can benefit from working in the different subsystems that compose a nanosatellite.

Recently, this methodology has been adopted for nanosatellite development at the Johns Hopkins University in USA and at the Observatoire de Paris' CERES campus. The latter made use of student teams and some lessons learnt are described in [7]. Their designing process is described below.

A first design cycle was carried out applying a concurrent engineering model named by ESA the "Spiral Model". The iteration starts with a mission requirement analysis that leads to the actual mission analysis. Then, the subsystem design step takes place and later it is followed by a design verification. Finally, risks are assessed before re-examining the mission requirements, completing the iteration. This cycle took 600 h of study. Some conclusions mentioned by the author include how time consuming is to manage a team of nine students that does not have real engineering experience and that shows heterogeneity in their works. One issue that happened was a deep misunderstanding of the problem that was tackled in time by an intermediate study report.

The second design cycle followed the agile principles. A common workspace (a FTP server) was set up. Each team of designers had a folder where to submit their deliverables. Important and valuable deliverables (documents, software, specifications, test routines, etc.) were in a read-only folder that was frequently updated by the project manager, with backups of previous iterations.

During this cycle, there were periods of time, called "runs", during which all efforts were concentrated towards a specific goal, with a duration of two or three weeks. The "chairman" oversees the run, usually a system engineer, the project manager or the deputy of the systems engineer. He/she requests every designer to deliver their work in their folders

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before a deadline and asks for the roadmap that the designer is going to follow in this run. Right after the deadline, the chairman analyses the deliveries and prepares a meeting that everyone attends, and where they have time to present a topic of interest, discuss the feedback and checks the deliveries. Finally, the chairman decides what is saved in the common data archive, with a confidence level of the results.

Other important roles that are set for each iteration are the “tracker” and the “testman”. The first one is in charge of preventing misunderstandings and bad communication between the different designers. The testman must test the project and advise the designer about possible improvements to make the tests more accurate, useful and usable by others.

This methodology can be combined with the concurrent engineering approach very easily and it does not require a linear flow as rigid as the traditional one: some subsystems could be more developed than others, for the flexibility and adaptability of these principles can accommodate easily major changes.

2.4 Methodology for CubeSat student projects in Aalborg University

Alminde et al. [8] and Larsen and Nielsen [9] collect lessons learnt from the development of three student satellite projects based on the CubeSat standard.

The authors highlight the importance of setting clear objectives and the available means to achieve them. The organisation was divided in two parts: the management team (four people, that also acted as supervisors for almost all groups) and the student groups. These two parts joined in the system engineering group, where the four managers and a student for each group steered the project. The student also acted as responsible system engineer for their subsystem. Another seat was available for the rest of the students, so all could get a feeling of the system engineering part.

Since the line between overmanaging and undermanaging is very thin, after a scheduled review the manager team only jumped in when important problems arose, and most of the times it was enough to make the students aware of it. Also, when students lost focus on the project because of other academic requirements (like exams periods), a 2-day workshop was organized to get thing back on track.

Finally, among the final recommendations are to keep the interface specifications very clear and force the student to keep them updated and discussed in the system engineering group. Also, to keep the students inspired it is important to have a first prototype early in the project. It is important to give a lot of responsibility to the students, so they become more devoted to the project and try to make a good job.

2.5 Methodologies followed by the members of the NANOSTAR consortium

The main objective of the first task of WP3 is to make an inventory of the methodologies already in use by the NANOSTAR partners. For that, a survey was sent to them to get some insight of the knowledge in satellite (or nanosatellite) development of the rest of the partners.

The result is that the majority of the members are familiar with the ECSS and the systems engineering approach, use typical project planning tools like the Gantt diagram, have previous experience in satellite development (most with nanosatellite development) and are used to involve students in their satellite programmes.

In the case of Institut Superieur de l’Aeronautique et de l’Espace, several CubeSats are in development, with student participation. One of these projects has been selected for ESA Education Office’s programme *Fly your Satellite!*, so it is assumed that an ECSS-based systems engineering approach is followed. However, their response to the survey suggests that they follow CNES methodology for CubeSats. Regarding project management, typical tools like the Gantt diagram are used. The project is divided in phases proposed in the ECSS, with the proposed reviews. Students are involved throughout all phases, their number changing with the necessities of the phase.

Universidad Carlos III de Madrid has no previous hands-on experience in satellite development, but in their master’s degree in Aerospace Engineering there is a course project related to a preliminary design given some top-level requirements. The professors prepare these requirements and guide small student teams throughout the project, similarly to what is proposed for the first phase of the Student Challenges.

Instituto Tecnico Superior de Lisboa, this institution has previous experience in nanosatellite development thanks to a 1U CubeSat participating in ESA Education Office’s programme *Fly your Satellite!*, therefore, a systems engineering methodology based on the ECSS standards is assumed.

There are three CubeSat projects currently Université de Montpellier in development with student collaboration, and already two 1U CubeSats. Since they have participated twice in ESA Education Office’s programme *Fly your Satellite!*, again it is assumed that their methodology is based in a systems engineering approach based on the ECSS standards.

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2.5.1 Universidad Politécnica de Madrid

The UPM experience is focused on small-satellites development, for in-orbit technology demonstration, with student participation [10].

The UPMSat-1 was a 50-kg microsatellite developed under the guidance of Prof. Sanz-Andrés. This satellite was successfully launched in 1995, and represented a joint effort from professors, students and other staff of the School of Aeronautical Engineering of UPM. According to Swartwout and Jane's work on university-class satellites, UPMSat-1 mission should be classified as Educational and Technological, because it combines both the purpose of training students and the purpose of being a technological demonstration (i.e., space qualification). This project produced a successful collaboration between the Aerospace Engineering school and the Telecommunications Engineering school of Universidad Politécnica de Madrid (UPM), in order to develop the on-board computer of the satellite.

The UPMSat-2 is a 50-kg university-class satellite. This is a long-term project that started in 2009. UPMSat-2 mission was initially planned as a challenge for the IDR/UPM staff in order to continue with the satellite program initiated with UPMSat-1. During the first part of this project, from 2009 to 2013, a first engineering and flight model was produced. After the delay of the initially planned launch20, a new model has been produced, involving students from the Master in Space Systems (MUSE) in the project. The mission has suffered a second delay in relation to the launch, the most probable date being by 2019.

the UPMSat-2 mission represents the framework for a successful collaboration between many partners. Among them, it should be mentioned the IDR/UPM Institute (as the leader of the project), the STRAST research group from UPM (responsible of developing the UPMSat-2 on-board and ground control station software) and several companies that supply instruments or advise.

One of the main characteristics of the UPMSat-2 is that it is a non-standardized satellite. The entire structure and most of the subsystems have been designed, built and tested in the UPM. This allows students to be present in all phases of a satellite project and brings their experience closer to what they would experience in a higher level mission. On the other hand, not resorting to standard solutions lengthens times, increases costs and limits launching opportunities. Taking the educational aspect as the key goal, an ECSS-based system engineering approach is followed for the project development, being the projects divided in ECSS proposed phases (an associated reviews), and making use of usual project management tools.

In relation to the educational aspects of this project, two different paths have been explored. On the one hand, the professors involved in the project have offered some lines of work as a part of their duties as university professors, these work load being mostly carried out through final year degree projects in the Aerospace Engineering Bachelor's degrees and doctoral studies. On the other hand, once the Master in Space Systems (MUSE) was organized, the UPMSat-2 became the perfect platform to train the students of this master in space technical requirements at professional level, taking into account that the main objective of their work is a real mission.

Several final-year-degree-projects related to the UPMSat-2 development have been carried out. Besides, it should also be pointed out that the academic programs at the School in Aeronautics and Space Engineering of Universidad Politécnica de Madrid (UPM) allow the students to do some training in engineering companies as part of the academic load. Even more, the work carried out by the students during these training periods can be linked to their final year degree project, increasing its academic benefits.

Until now, approximately 30 final year project works have been developed in aspects related to the UPMSat-2 mission, these works being mainly focused on mission analysis, integration, verification and quality assessment (these works included documentation development, and tests planning and verification procedures), requirements definition, structural analysis (MSC Nastran) and optimization of the different parts (pillars, trays, panels...), attitude control (definition, requirements, and analysis of different solutions), power subsystem (requirements, sizing, and predesign, including space-qualified parts selection) and the on-board computer software definition, testing and documentation following ECSS E40/E80/Q80 standards.

Doctoral studies and programs towards the more qualified Ph.D. graduates are a key factor in academic satellite programs. These high profile students can share their research with other students from bachelor's and master's degrees. Furthermore, they are also and important asset for the program in relation to companies from the space sector, taking into account that these companies are normally interested in hiring the most trained personnel. At present, three Ph.D. dissertations have been successfully carried out at the IDR/UPM Institute directly related the UPMSat-2 project. Besides, seven more Ph.D. students are currently working in several research lines associated to the UPMSat-2 mission.

From the educational point of view, the UPMSat-2 mission has proven to be an extremely useful tool for the Master

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in Space Systems (MUSE). The different aspects of the mission (planning, developing, testing, systems integration, subsystems and payloads analysis) cover almost all the academic load of the master. However, beyond this academic load It represents a space engineering framework that allows the student to train their skills in one of the most demanding working environments, it boosts the student's motivation, increasing their work capacity and improving their results, and the tasks carried out by the students are highly appreciated by the space-engineering sector, this fact being based on the students employment rates once they are graduated.

The predesign of the missions is performed at a Concurrent Design Facility (CDF). The CDF provides an environment for close interaction among the designers and subsystem specialists. The facility itself consists of 13 computer stations, specific multimedia hardware for teleconferences and presentations, a server for data storage, and a software infrastructure for the generation of the mission design and data propagation between disciplines in real time. It was established in 2011 and operated with Concurrent Design software.

Taking advantage of the CDF students of the Master in Space Systems (Máster Universitario en Sistemas Espaciales, MUSE) are experiencing the opportunity to deal with the concept of Concurrent Engineering in two ways:

- Students have the chance to participate in the CDF modules development and implementation as part of their Study Cases or Final Projects.
- 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 project-based learning activities).

At the early days of the CDF, a Concurrent Design software was developed, using Python language, by IDR/UPM, called Concurrent Design Application. At this design phase, multiple modules for the study of different spacecraft subsystems were elaborated by students during their internships in IDR/UPM and as final dissertations in both, bachelor's and master's degrees.

The main disadvantage of this approach is the excessively amount of time required to train students who would not continue their work next year. Additionally, most of the modules were closed designed and were independently developed, which made a harsh task to integrate them together. These modules exported their results into different formats and used their own data base.

This software developed by IDR/UPM was substituted in 2015 by the Open Concurrent Design Tool (OCDT), a server software package developed under an ESA contract to enable efficient multi-disciplinary concurrent engineering of space systems in the early life cycle phases. Due to the fact that the OCDT system employs Microsoft Excel as client application and that it is widely known by bachelor students, it was decided to develop Excel calculation modules for the design of spacecraft subsystems. Nevertheless, as the achievable level of design and analysis when using Excel is limited, the modules are usually focused to employ an external design software, depending on the subsystem, to export data and import results. These modules are similar to those developed for the SCDT4.

In order to transfer efficiently the acquired knowledge by the students working in the CDF, a collaborative frame of work between first- and second-year students was established [11, 12]. This frame involves the development or update of the available modules and also the establishment of a learning methodology for the continuous improvement of the CDF environment. The collaboration among students is intended to facilitate the learning process of concurrent engineering and to improve their skills in terms of communication and design thinking. A group of students from second-year organized a set of activities to train first-year students under the direction of professors and IDR/UPM staff. Such activities were defined to be repeated each year so the current first-year students will take charge of the training of new students about Concurrent Design and the CDF modules improvement.

2.6 Collaborative methodologies

Regarding collaborative methodologies that can be useful for the students and the development of nanosatellite projects, three parts are suggested: a remote archive, following a concurrent engineering approach and the use of version control tools.

A file-sharing service can be set up to submit every digital file in the project for everyone to see. Nowadays, online tools like the one described also include document, spreadsheet and slide processors where several people can work at the same time. This accelerates the creation of important documentation that may be required by the project and any external agents.

Concurrent engineering is a method of designing and developing products for the space sector. Contrary to traditional design methods, in concurrent engineering all subsystems are designed simultaneously. This is a far more efficient

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way of working, but comes with its own unique challenge: solutions in one area that could impact the design of another subsystem must be identified and communicated between teams instantly. Although concurrent engineering is a more complicated process to begin with, in effect it allows mistakes to be identified, and rectified, earlier, therefore reducing the overall design time. Concurrent engineering has been taught in MUSE since the very beginning [11–13], as aforementioned.

Finally, source version control tools are very common in software engineering to keep track of the changes made in the source and non-source files in a software project. The same tools can be applied in a similar way to any type of project.

One of these tools is *Git*, and is going to serve as an example to explain how these programmes work. *Git* is based on repositories, a place where things can be stored and can be found, and works storing changes made to the files tracked in the repository, allowing to go back to previous snapshots any time. In the case of text-based files, it is also possible to see the differences and merge changes made by different collaborators. Another important concept is the use of "branches": it is possible to create a deviation of the project based on an old snapshot and advance with the project with two different approaches, and then compare both branches later and even merge them together. It is usual to have a remote repository where everything is stored and to work on a local repository, and then pull or push changes from and to the remote repository, similarly to how ESA's OCDT for concurrent engineering works.

2.7 Summary

Given the previously shown information, it is interesting to propose a methodology based on the systems engineering approach found in the ECSS standards, since most of the members of the NANOSTAR consortium are already familiar with it, may be with some simplifications and some tailoring for nanosatellite projects.

Regarding collaborative methodologies, the use of concurrent engineering in early phases it is already planned. Outside of the CDF, it is interesting to use an online repository where all information should be available for all members of a student team, and a version control tool that could ease keeping track of the evolution of the project.

3. NANOSTAR documentation webpage

The NANOSTAR documentation webpage (shown in fig. 2) is the result of establishing a nanosatellite development methodology and a collaborative methodology. The objective is to provide the students participating in the student challenges a quick access and an overview of the parts of a nanosatellite, how they can organise, manage and plan its development, and an introduction to the ECSS.

The first section of the documentation serves as an introduction to the nanosatellite and CubeSat world, considering the *CubeSat Design Specification* [14] and providing resources for finding COTS components.

The next chapter is the management methodology, where users will find a description of systems engineering applied to space projects, concurrent engineering and agile development. These methodologies were selected as a result of the literature review compiled in section 2. Systems engineering is the traditional way of working in space projects and almost all partners have experience with it. Regarding concurrent engineering, it is a methodology that ESA and NASA are backing intensively for students, and therefore the NANOSTAR partners thoroughly recommend the usage of a CDF and are developing their own software solution based on CNES' CIC concurrent software. Finally, agile developing is a methodology used in software engineering that it is being tested for hardware projects and whose principles blend very well with concurrent engineering. The methodology is proposed to the students.

As an introduction to nanosatellite design, an overview and some guidelines are provided for each subsystem and aspect. These subsystems are command and data handling, attitude determination and control, communications, configuration and preliminary sizing, ground segment, launcher, mission analysis, payload, electric power, propulsion, structures, systems engineering, and thermal control. The preliminary design guides are based on the following references:

- Peter Fortescue et al. *Spacecraft systems engineering*. John Wiley & Sons, 2011 [15]
- JR Wertz and Wiley J Larson. *Space Mission Analysis and Design, Space Technology Library*. Microcosm Press and Kluwer Academic Publishers, El Segundo, CA, USA, 1999 [16]
- Malcolm Macdonald and Viorel Badescu. *The international handbook of space technology*. Springer, 2014 [17]
- Mukund R Patel. *Spacecraft power systems*. CRC press, 2004 [18]
- J Jaap Wijker. *Spacecraft structures*. Springer Science & Business Media, 2008 [19]
- José Meseguer et al. *Spacecraft thermal control*. Elsevier, 2012 [20]
- Howard D Curtis. *Orbital mechanics for engineering students*. Butterworth-Heinemann, 2013 [21]

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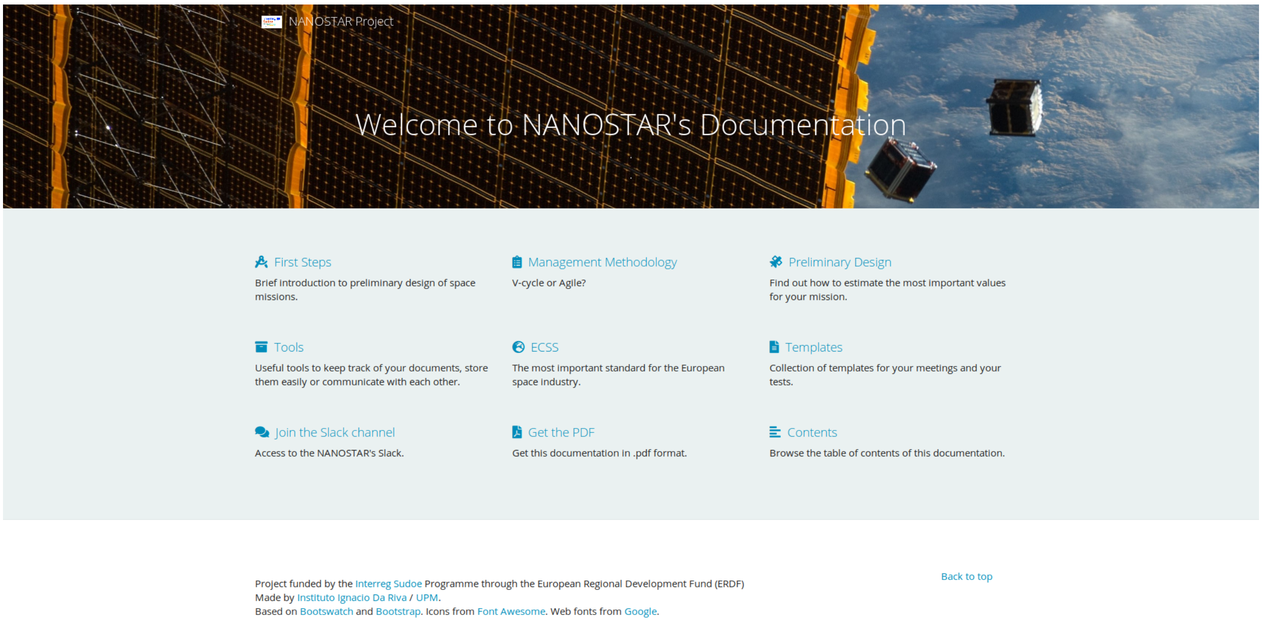

Figure 2: Homepage of the NANOSTAR documentation webpage (05/06/2019).

- James R Wertz. *Spacecraft attitude determination and control*. Vol. 73. Springer Science & Business Media, 2012 [22]
- George P Sutton and Oscar Biblarz. *Rocket propulsion elements*. John Wiley & Sons, 2016 [23]

Also, there is a quick overview of each branch and subbranch the ECSS, since most actors in the European space industry require their compliance. Apart from that, an index of some interesting tools for working collaboratively in a project of these characteristics is included, as well as some templates in Microsoft Office Word and Microsoft Office Powerpoint that the students can use for their documents.

4. The Student Challenge

The Student Challenge consisted in predesign a small satellite fly-by mission to the Moon, with some science data acquisition during the periselene pass, e.g. from altitudes above the Moon's surface as low as 100 km. This science data shall be a few pictures of the lunar soil taken by a minimal onboard payload like an optical camera.

The objective of the team was to propose a feasible solution for the challenge, which includes performing the requirement flow-down of the mission, defining and sizing all the relevant subsystems, carrying out the mission analysis, estimating the performance of your system, and justifying that your solution satisfies all top-level mission requirements and deals with the constraints.

A total of 15 multidisciplinary teams from all the partners participated in the Challenge, submitting their solutions by 13 May 2019. The total number of registered students raised to 103 students. Members from all NANOSTAR institutions composed the Evaluation Committee, who selected the winners based on the following criteria:

- Compliance with the top-level requirements of the mission
- Project consistency, risk analysis, and physical soundness
- Maximization of the mission figures of merit
- Solution innovativeness
- Document quality
- Presentation quality
- Team management and organization
- Team size, multidisciplinarity, gender balance, and interinstitutionality
- Correct usage of NANOSTAR resources, tools, and methodology

The different winners [24] presented solid solutions with respect to their categories: Best Team, Best Predesign

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Document, Most Innovative Mission, Best Management Practices and Best Oral Presentation.

Moon Invaders, winners of the Best Team category, is a team with four students from UBI and one from UPM that presented a 6U CubeSat weighting 14 kg that performs two flybys to the Moon's south pole. A camera and two spectrometers compose the payload, and 72 solar cells provide the necessary power to operate.

Two teams from UC3M, *CubeSat Chefs* and *Janus-X*, won at the Best Predesign Document and Most Innovative Mission categories, respectively. For Best Management Practices, *Eirb'Strong* from ENSEIRB-MATMECA. They used Trello[1] as a project management tool, using its board- and tasks-based system to keep track of the work done and to-be-done. Finally, *Selene* won the Best Oral Presentation category, which is a team from UPM and composed by students from the Master of Space Systems (MUSE).

With such a great success, and since more universities have stated their interest in participating, the student challenge is going to be launch again in September 2019.

5. Final comments

The NANOSTAR project is a join effort by universities, institutions and representatives of the space industry from the South-West of Europe, concretely Portugal, Spain and the southern France. The objective of this project is to develop the academic and industrial fabric of the space sector in this region through the participation of students in challenges that will provide them with the tools to contribute to this field.

The Research Institute for Microgravity "Ignacio Da Riva" (IDR), as part of Technical University of Madrid (UPM) is a partner in this consortium funded by Interreg-Sudoe, and is in charge of establishing the methodology to develop nanosatellite projects collaboratively.

For that, as a first step, an inventory of existing methodologies for nanosatellite development projects has been completed as a first step. It reflects the reality of the space sector and the new trends in project management that are starting to grow with the New Space movement. For example, the inclusion of the Agile methodology, very common in software industry nowadays was unheard until some years ago with the development of the nanosatellite sector. Regarding the NANOSTAR partners, the results of a survey suggest that most of them follow a more traditional systems engineering approach. Therefore, both methodologies are proposed to the students, so they can choose and adhere to one of them.

To be more accessible to the users, the documentation is published in a web format that contains information about the nanosatellite and CubeSat world, guidelines for preliminary design, early sizing and estimation of a satellite and its mission, an overview of the ECSS applied for nanosatellite projects, the description of these two work methodologies for nanosatellite projects, interesting tools for a collaborative environment and useful templates for the student challenges.

Finally, with 103 distributed in 15 teams, the Phase I Student Challenge has been a success. The Best Team was *Moon Invaders*, composed by four students from Universidade da Beira Interior (UBI) and one student from Universidad Politécnica de Madrid (UPM). In September 2019 a new challenge will be launched.

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