UNIVERSIDADE DA BEIRA INTERIOR
Engenharia

Using Project Management methodologies in a CubeSat project

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Dissertação para a obtenção do Grau de Mestre em

Engenharia Aeronáutica

(Ciclo de estudos integrado)

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Covilhã, Outubro de 2017

Acknowledgments

There are many people whom I would like to thank for helping me over the last six months. To them, I am sincerely grateful.

Firstly, Professor José Manuel Mota Lourenço da Saúde, for making this dissertation possible. I am truly thankful for the given opportunity to work with CEiiA.

Further, my gratitude goes to my supervisors at CEiiA, Tiago Rebelo, André João, and Raquel Magalhães, all of them Professional Engineers. You always dedicated your time helping me, indicating me the right path to follow. I have greatly appreciated your support. Thank you for everything.

At the same time, I would like to thank CEiiA for the given opportunity. It was an amazing experience, reaching me as person and future professional. Moreover, this gratitude obviously includes CEiiA's Aerospace and Ocean Unit. I have no words to describe your kindness and all the things you have done to help me finish this dissertation.

Not less important, I want to thank to my teammates, the MECSE team, who always tried to clear my path, and help on whatever comes. You are the living proof that teamwork is the right path to achieve great things.

I would also like to thank to all the other colleagues who were working on their dissertation too, without you my journey for sure would not be so good and pleasant. Some special thanks for Jorge Monteiro and Ludjer Rodrigues for your friendship and companionship, I will never forget that.

A special gratitude for my girlfriend, Ana Costa, who was always there to support me, with a kind word on the right moments, in those moments when my faith was shaken. I have no words to describe how important you were to lead to good port this master dissertation.

Thank you all whom helped me during this dissertation, especially a huge thanks to my friends André, Eduardo, João, Luís, Rafael, Rita, Vítor. More than helping me, you are always there for me and available to hear my complaining.

Finally, I would like to thank all my family for their unconditional love. Everything I am today, was tailored from your support. I am forever thankful to my parents, Olímpio and Lígia, for providing me the opportunity to make this dream come true.

Dedication

This M. Sc. dissertation is dedicated to the most important persons of my life, my beloved parents,

…Olímpio Dias Pardal Bispo

…Lígia Maria Dias Lopes

“Given ships or sails adapted to the breezes of heaven,

there will be those who will not shrink from even that vast expanse”

- Johannes Kepler

Letter to Galileo, 1610

Resumo

Em 1999, na Universidade de Stanford em cooperação com a California Polytech State University, desenvolveu o conceito de CubeSat para facilitar a participação de estudantes em projetos académicos espaciais.

Atualmente os CubeSats são cada vez mais comuns, com um aumento do número de projetos e lançamentos bem-sucedidos cada vez maior, havendo já quem defenda a possibilidade de utilizar este tipo de satélites pequenos, "low-cost" para a substituição e renovação de constelações de satélites maiores, mantendo ou aumentando as capacidades atuais, com um custo similar.

A Universidade da Beira Interior e os seus alunos pretendem desenvolver um CubeSat capaz de testar os efeitos do plasma no fenómeno de "blackout" durante a reentrada na atmosfera terrestre de um objeto, numa tentativa de validar um modelo numérico que já se encontra em estudo e desenvolvimento na Universidade.

O propósito desta dissertação é a implementação de metodologias de gestão de projeto, focada na gestão do planeamento, da cronologia, da documentação e do risco, de um projeto de CubeSat desenvolvido em cooperação com a indústria.

A introdução de uma metodologia foi implementada com o projeto já em desenvolvimento, o que dificultou a tarefa de gestão do projeto, sendo necessário começar por gerir todo o trabalho já realizado. Posto isto, a tarefa inicial foi a elaboração de um cronograma visando as tarefas já realizadas e a realizar no futuro, seguindo-se um levantamento preliminar dos riscos inerentes ao projeto, bem como a gestão documental necessária para que se torne possível um acompanhamento do projeto a membros exteriores à equipa de trabalho.

Palavras-chave

Gestão de Projeto (PM), CubeSat, gestão de planeamento, gestão de risco, gestão documental, gestão da cronologia, Work Breakdown Structure (WBS), lessons learned.

Abstract

The CubeSat designation was developed in 1999 at Stanford University and the California Polytech State University to facilitate the participation of students in academic satellite projects.

Nowadays CubeSats are a common reality, facing an increasing of projects and well succeed deployments, which made some authors consider the possibility of replace and renew the existing constellations of bigger satellites for this type of small, low-cost satellites, maintaining or increasing their actual capabilities for a similar price.

The University of Beira Interior and its students pretends to create an entire CubeSat, which would be capable to test the Radio Frequency Blackout during re-entry on Earth atmosphere had arisen, to support a numerical model already in development and testing at University of Beira Interior.

The purpose of this dissertation is to implement Project Management methodologies, focusing on planning, schedule, documentation and data, and risk management, on a CubeSat project developed in cooperation with University and industry.

Project management was implemented after the project kick-off, being necessary to organise the work already done. The first step was the elaboration of a schedule for the tasks (already done and further work), a preliminary risk management, and the essential documentation management to allow the proper monitoring of the project from the team and external entities.

Keywords

Project Management (PM), CubeSat, Management planning, risk management, documentation management, schedule management, Work Breakdown Structure (WBS), lessons learned.

Contents

List of Figures

List of Tables

List of Acronyms

AIR	Azores International Research
AMSAT	Radio Amateur Satellite Corporation
ANSI	American National Standards Institute
AOCS	Attitude and Orbit Control Subsystem
AR	Acceptance Review
CCPM	Critical Chain Project Management
CDF	Concurrent Design Facility
CDR	Critical Design Review
CE	Concurrent Engineering
CEiiA	Centre of Engineering and Product Development
CIDL	Configuration Item Data List
C-MAST	Center for Mechanical and Aerospace Science and Technologies
CPM	Critical Path Method
CRM	Continuous Risk Management
CRR	Commissioning Result Review
DMP	Data Management Plan
DoD	Department of Defence
DSM	Design Structure Matrix
ELR	End-of-Life Review
EMG	Electromagnetic Generator
ESA	European Space Agency
EVM	Earned Value Management
ExB	Electromagnetic
FMEA	Failure Modes and Effects Analysis
FRR	Flight Readiness Review
GPS	Global Positioning System
HQ	Headquarters
ID	Identification
IDM	Integrated Design Model
KDP	Key Decision Point
L-C	Likelihood-Consequence
LP	Langmuir Probe
LRR	Launch Readiness Review
MDR	Mission Definition Review
MECSE	Magnetohydrodynamics/ Electrohydrodynamics CubeSat Experiment
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration

PBS	Product Breakdown Structure
PDR	Preliminary Design Review
PERT	Program Evaluation and Review Technique
PM	Project Management
PPLM	Project-Product Lifecycle Management
PRA	Probabilistic Risk Assessment
PRR	Preliminary Requirements Review
QR	Qualification Review
RIDM	Risk-Informed Decision Making
RIDs	Review Item Discrepancies
SD	System Dynamics Method
SRR	System Requirements Review
tE	Three-point Estimation
tM	Most Likely
TMA	Technology Maturity Assessment
tO	Optimistic
tP	Pessimistic
TRL	Technology Readiness Level
UBI	University of Beira Interior
WBS	Work Breakdown Structure

Chapter 1 - Introduction

1.1 Motivation

Since the mid-twentieth century, space exploration has evolved from just observe the stars and other celestial bodies, helped by telescopes, to space flights orbiting the Earth (Sputnik 1 on 4 October 1957) and then to first manned Moon landing on 20 July 1969 (Neil Armstrong and Buzz Aldrin on Apollo 11) [1], changing completely the way humankind saw space. This was like the start of an Era, the space exploration Era. Nowadays, manned moon missions are over (till 2020, when NASA pretends to launch EM-2 mission) [2] but many other space missions became a reality, like probes exploration, satellites equipped with many kinds of technology, to allow us to "go" further and further in space, acquiring more and more detailed information about what is around the Earth.

During the last two decades, technological research and developments had a big impact on electronics, making components smaller, sophisticated, cheaper and with increased performance, providing more reliable systems and creating education opportunities for industry and academia which were too expensive to proliferate before [3]. Not only electronics helped small satellites becoming more accurate, but also microelectromechanical systems, triple-junction solar cells, lithium-ion batteries, the Global Positioning System (GPS), internet and improved modelling software made them more reliable and appealing [4].

Initially, satellites with less than 200 kg weight were called microsatellites, having no distinction on nomenclature below that weight and their first space missions start near fifty's decade end, increasing exponentially over a decade and declining after that until Russian Strela mission that balanced the microsatellites launches between 1970 and 1993, being almost the only launches of this satellite type during 1977 to 1987. The nature of this decline was in part because the early 1960's microsatellite missions evolved and they were replaced by bigger and heavier satellites, creating the known "Small Satellite Doldrum" which did not impact the experimental and educational spacecraft launches by Radio Amateur Satellite Corporation (AMSAT) in part because they did not want or could not afford the expenses of big satellite communication capabilities [4].

The CubeSat designation was developed in 1999 at Stanford University and the California Polytech State University to facilitate the participation of students (mostly from science and engineering fields) in academic satellite projects. The embryonic phase is characterized by simple demonstration missions (commonly referred as BeepSats), performed by educational institutions supported by their low cost and short project schedule since the kick-off until the launch day [5]. This academic projects are a challenge in many ways due to their short development time and complexity, and it could be greater if a multidisciplinary team were not carefully selected [6].

The technology evolves and recently has been proposed that CubeSats can replace or renew existing constellations, maintaining or increasing performance for a similar price [5].

Nowadays projects are considered as the driving force for many organisations and industries, making project management discipline an important factor of change efficiently and effectively and a powerful tool in an extremely competitive world [7]. Projects are even referred as an important way to structure work across the organisations, being one of the most important organisational developments [8].

[Project Management] "… changes over time but the basic business premise never changes: Accomplish the right thing right the first time within justifiable time, resources, and budget. Projects are the means for responding to, if not proactively anticipating, the environment and opportunities of the future" [7].

The purpose of this dissertation is to implement Project Management principles - focusing on planning, schedule, documentation and data, and risk management - on an on-going small satellite project (CubeSat) whose aim is to research the influence of a magnetic field on plasma layer during the re-entry phase, to allow communications between ground and the spacecraft while it occurs. Although communications blackout period being an undesirable obstacle on space exploration, it is tolerable, but is imperative mitigate this phenomenon to materialize some dreams [9].

For the sake of completeness, Magnetohydrodynamics/Electrohydrodynamics CubeSat Experiment (MECSE) is a space project developed in an academic context, based on voluntary work by a group of students and teachers, in partnership with the Centre of Engineering and Product Development (CEiiA), to produce and ship to space a nanosatellite with the goal of evaluate the effects of a magnetic field on plasma during a spacecraft re-entry phase, where the ultimate goal is to mitigate or eliminate the radio frequency communications blackout caused by the plasma layer surrounding the spacecraft in this phase.

Within this context, CEiiA, as a technological company, challenged the author to be part of this project, contributing in Project Management development and implementation.

1.2 Objective of research

The objective of this research work is to address the issue of project management in order to implement relevant methodologies thus optimising the managing process of a CubeSat experiment.

1.3 Research goals

Pursuant to the objective of this research the following are the goals set, that is:

- Implementation of a management planning, focusing on project lifecycle phases, tools, and methods to manage changes during the project;
- Elaboration and implementation of a schedule management, with the definition and management of project timeline, milestones and its critical path;
- To prepare and share with the project members a documentation and data management, making the communication between all parts easier and information exchange much more efficient and regulated;
- To perform a risk analysis to ensure the correct project execution, which will allow reduction of costs/schedule glides, and if some programmed tasks will not track project to its goals or can be replaced by better/easier tasks.

1.4 Research limitations

The implementation of Project Management methodologies presented the following limitations for the purpose of this dissertation:

- The standards and guidelines adopted are based on space systems, focusing NASA and ESA experience;
- Due to the educational framework, the project does not follow a commercial approach. The objective of the project is not related to profit generation, instead being funding by government;
- The research focus is directed for space systems, constraining the methodology of Project Management;
- Due to the project had started before the implementation of Project Management methodologies, the implementation process does not displays the preparation for implementation of the project.

1.5 Research strategy and document structure

The research strategy undertaken in this document comprises three sequential steps:

1. Acquiring relevant information about every subject described in the document;
2. From all data, choose the most significant and essential;
3. Implementation of it on an on-going project (MECSE).

This document is structured in a coherent and logical manner. The chapters' schematic is as follow:

Chapter 1 starts with the motivation to the research problem, describes the objectives and goals, presents the strategies adopted, refers the research limitations, and the document structure.

Chapter 2 is dedicated to CEiiA Corporation, and its Aerospace and Ocean Engineering Area, describing briefly of what is being done and the contribution for this dissertation.

Chapter 3 provides a State-of-the-Art of Project Management methodologies, emphasising the team building, the lifecycle and reviews of a project, the communication methods and channels, the management planning, the schedule management, the risk management and the documentation and data management.

Chapter 4 presents the experimental procedure, focusing on implementing the methodologies of Project Management on MECSE project, such as its schedule, risk plan, documentation management, and approval chains.

Chapter 5 presents the conclusions from the implementation of all the topics referred before on the concrete case studied, the difficulties encountered during this dissertation, and the areas which need further investigation or more data acquisition before implementation.

Chapter 2 – Research framework

2.1 CEiiA brief history

CEiiA is a Portuguese Centre of Engineering and Product Development, created in 1999, that designs, implements and operates innovative products and systems, alongside with its partners, for high-tech industries, such as, the aeronautics, automotive, urban mobility, ocean and space ones. CEiiA's vision is to establish Portugal as a reference within these industries, particularly in the development of technologies, products and systems, conceived, industrialized and operated from Portugal.

CEiiA is the engine of a strategic cluster focused on the mobility industries, an area in expansion and development, based on innovation and creativity, with the goal of dynamization and reinforcement of technological innovation.

2.2 Dissertation outputs

Within this highly innovative ecosystem, CEiiA's Aerospace and Ocean Engineering Area arises as one of the most recent working areas of CEiiA. The CubeSat project works as a benchmark for future works on this field, allowing CEiiA gather knowledge and know-how on space projects, at the same time as academic students. In this context, the author of this dissertation was challenged to join an ongoing project team to implement project management guidelines.

The benefits generated by this dissertation for the Aerospace and Ocean Area are, mainly, the standardisation of MECSE Project Management methodologies aligned to CEiiA's methodology, ensuring a better understanding and traceability of the project.

Chapter 3 – State of the Art

This chapter presents some project concepts essentials to understand the need for project management on organisations. Due to having a close connection, the first sub-chapter is dedicated to project management and systems engineering.

The following sub-chapters are divided by project management methodologies, emphasising those used during the implementation on MECSE project.

3.1 Background

3.1.1 Systems Engineering

Systems engineering is a methodical, interdisciplinary approach governing the total technical effort to transform requirements into a system solutions [10]. A “system” is a construct or collection of different elements that together produce results not obtainable by themselves alone. These elements can be people, hardware, software, facilities as many others, that is, all things required to produce system-level results. The value added by the system beyond that contributed by each part alone is primarily created by how they are interconnected [11].

The purpose of systems engineering is to “know” the system so that it accomplishes its missions safely in the most cost-effective way possible, providing the most effectiveness with the least expensive solution, despite the amount of design solutions available [11].

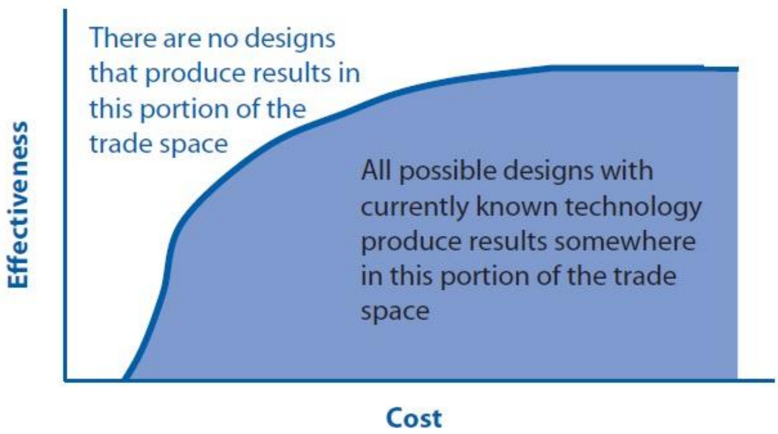


Figure 3.1 – The enveloping surface of nondominated designs (adapted from [11]).

Figure 3.1 shows the infinite domain of solutions taking in care its cost and effectiveness, helping understand the real deal about choosing one instead the other. To support the decision a design trade-off studies must be performed and when the starting point for a design is inside the envelope, there are alternatives that reduce costs without decreasing effectiveness or alternatives that improve effectiveness without a cost increase. The harder part of the decision-making process becomes when the design trade-off study requires trading cost for effectiveness or the opposite [11].

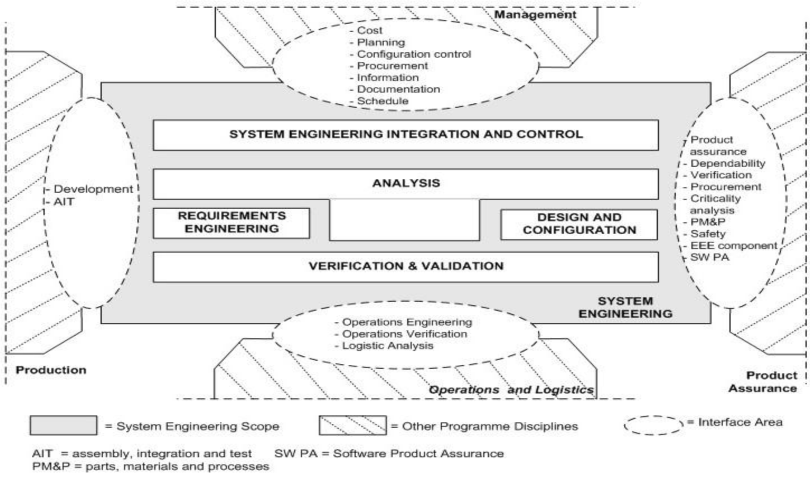


Figure 3.2 – Systems Engineering, sub-functions and boundaries (adapted from [10]).

In a project context, the system engineering function is generally implemented by a system engineering organization of the supplier which is responsible for transforming the requirements of the customer into a system solution delivered by the supplier [10].

Concluding, *“systems engineering is about looking at the “big picture” and not only ensuring that they get the design right (meet requirements) but that they get the right design”* [11].

3.1.2 Project Management

Project Management is a general discipline which provides a set of tools across almost all human activities, and it states that all actors must cooperate to reach the goals, increasing the effectiveness and efficiency of a complex activity. Project Management consists of the definition, implementation and execution of scheduled actions and verification that results match the expected outputs, which means that it requires careful thinking about what is pretended to accomplish, the needed steps to do it and the resources needed to take all those steps, always having in mind the “real world” (problems that, for sure, will appear, delays on deliveries, changes to goals, and others) [13].

This subject has emerged to respond to the necessity of new management methods, and it has been settled in three major pillars: the exponential expansion of human knowledge, the growing demand for a broad range of complex, sophisticated and customized goods and services, and the evolution of competitive markets for production and consumption of goods and services [12].

3.1.3 Project Management vs. Systems Engineering

Project Management has the task of planning, overseeing, and directing the activities required to achieve the requirements, goals, and objectives of the customer and other stakeholders within specified cost, quality, and schedule constraints. It can be divided in two major areas, with equal weight and importance, which are systems engineering and project control, and they interact in some aspects of the project. On their interaction, it is safe to say that systems engineering provides technical aspects and project control provides the programmatic, cost, and schedule aspects [11].

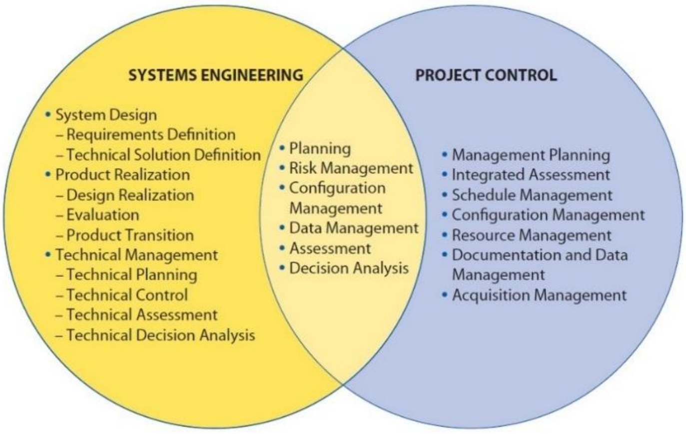


Figure 3.3 – Systems engineering in context of overall project management (adapted from [11]).

Systems engineering, as part of project management plan, define its activities according the project phases timeline. It also supports the project manager in the project reviews, and in the collection of experience gained, ensuring that all experience acquired (past activities data and parallel activities data) is systematically considered [10].

Management distribution, as a systems engineering task, it is an overlapping with the project management field of work, as shown on Figure 3.3. The systems engineers expect to have an overview over the whole system and the dependencies in the development process, so they can distribute tasks to perform and communicate the dependencies, and, based on psychological challenges occurring in an engineering environment, support the development team in solution finding and decision making, promoting objective criteria based analyses [11].

3.1.4 External commitments

Due to the inherent complexity of a space project, is usual state external commitments with other firms and/or facilities, with the objective of both parties take advantages from that [12].

These commitments could be in form of contracts, agreements, or operational plans, and they ensure that the enabling products will be available when needed to support the project lifecycle phase activities among other advantages like diversification of technical risk, avoidance of capital investment, and pooling of complementary knowledge [11], [12].

The stakeholders' choose criteria is extremely important to a well succeeded project because inadequate stakeholder involvement will lead to inadequate requirements and a resultant product that does not meet the stakeholder expectations [12].

The impact of external and/or internal commitments on the project manager is significant. The project manager is dependent on commitments made by people who, sometimes, owe little allegiance to the project, and so little loyalty to him, and over whom him has little or no authority at all. Concluding, quoting C. Cowen:

"Project partnering is a method of transforming contractual relationships into a cohesive, cooperative project team with a single set of goals and established procedures for resolving disputes in a timely and effective manner" [12].

3.2 Team building

3.2.1 Relevance of a good team building

Project teams are the cornerstone of any project, so their characteristics drive the project performance. Depending the aims of the project, the teams can vary on size, experience, qualities, availability and involvement of the participants. Focusing on a CubeSat project, it has to deal with different disciplines, which leads the team to be divided into smaller subgroups, usually by technical areas, making less clear which subgroup or person is affecting the performance of the project [6], [16].

Knowledge acquired by field research suggests that factors such as work and its structure, the business processes, the tools and techniques applied and the emotional skills of the members of a team have a great influence on the individual behaviour, which could contribute to the project team performance, evaluated by the factors shown on Figure 3.4 [16]:

Figure 3.4 – traits of a high performing team (adapted from [16])

Like every type of groups, the project team has to face the phenomena of group dynamics, increased by being a highly visible and focused team from whom are expected high performances. Attached to this comes the possibilities of malfunctions between the members performing a specific task [16].

Concluding, *"team building can be defined as the process of taking a collection of individuals with different needs, backgrounds, and expertise and transforming them into an integrated, effective work unit"* [16].

3.2.2 Important points to take care in team building

Nowadays, moved by the lightspeed changing business world, project teams should be flexible and able to dynamically and creatively work toward established objectives, which requires an effective networking and a close cooperation between all intervenient in the project. These environments require from the managers human and interpersonal skills to meet the complex demands [16].

Normally the project manager has to build the team starting from scratch or inherit one team not fully fledged and effective. The challenge in team building is to assemble an effective team respecting the following main constraints [17]:

- Budget constraint – despite the need for recruiting more people, sometimes the budget allocation will not allow it;
- Project being used as a dumping ground – other managers using the assemble of a new team as a way to allocate their team members they do not want or need;
- Selfish managers – the managers who hold the best workers of the field even when they do not really need them or when they are actually more useful in another task/ project.

Understanding these barriers is an important guideline to gather the best team possible despite the external constraints faced [16].

Team building is a process that involves strong leadership skills and an understanding of the surrounded environment, and it is particularly crucial in environments where complex multidisciplinary activities demand the skilful integration of many specialities [16].

3.2.3 Team building methods

The recruitment process plays an important role on the success of a project, being essential that the team has the right people on the right places.

"Managing global project teams is not for the weak or faint of heart" [16]. Observations from best practices demonstrate that specific working conditions emerge most positively associated with teamwork despite the complexities, organisational dynamics and cultural differences [16].

Normally, teams await for managers to provide directions for tasks to be executed but an alternative solution is to encourage teams to be self-directed or self-managed. In this case, the manager delivers the goal and rely on the workers' management efforts, giving them the feel of ownership, improving their morale and devotion which is reflected in better performances [19].

Another important factor for a good team building is the communication between all the members of the team, and some actions could be taken to foment it, such as start-up workshops and follow-up workshops [19]:

- <u>Start-up workshop</u> – its purpose is to establish communication and team building skills between the team members. It should be celebrated in a relaxed environment, if possible away from the daily routines, conducive to open discussion. It is important to select the appropriate facility which allows the accommodation of whole group;
- <u>Follow-up workshop</u> – this type of workshops is very useful to review the project and project team performance and they are the best way to introduce the new members to the project. It is recommended that these workshops occur periodically, aligned with the overall project duration.

3.2.4 Concurrent Engineering

Concurrent engineering (CE) is a systematic approach to integrated product development that highlights response to stakeholder expectations and encompass team values of cooperation, trust, and sharing. The objective of CE is to cut down the product development cycle duration through a better integration of activities and processes. Large amount of parallel work from different subsystems of the project are synchronised by exchanges between teams to produce consensus and decisions. Nowadays CE is widely accepted and is considered as an excellent alternative approach to a sequential engineering process [11].

Involving all team members in the design from the beginning lead to better and cheaper products as all aspects determining the final resulting design can be considered since the beginning. Concurrent engineering is not a quick fixing tool for the company's problems and it is not just a way to improve engineering performance, it is a business strategy that addresses important company resources [20].

3.2.4.1. Concurrent Design Facility

The concurrent design facility (CDF) infrastructure is based on the Integrated Design Model (IDM), which allows integration of all the subsystems tools and parameters in a unique design environment, arranged to facilitate communication [20].

At this facility, one of the unique characteristics is the integration of the computers, used to host the basic software, mainly consisting of office-automation products and specific engineering tools. The achieved quality results in short time revealed the value of such method, and the key elements of this implementation were set as being the process, the multidisciplinary team, the integrated design model, the facility, and the software infrastructure [20].

The equipment location and layout of the CDF presented on Figure 3.5 are designed to facilitate the design process, the interaction, the cooperation and the involvement of the specialists, with the particularity of the most related disciplines (the ones which interacts more) are close to each other. The central table displayed on Figure 3.5, is reserved for customers, support specialists, and consultants [21].

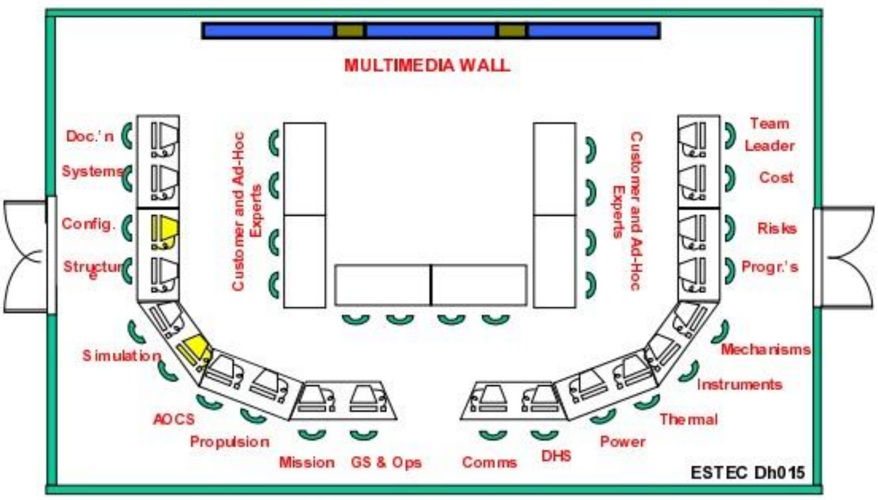


Figure 3.5 – ESA Concurrent Design Facility (adapted from [21])

3.2.5 Conclusion

Teamwork is increasingly important because change (in economy, society, culture, between others) continues to occur in an accelerating rate, which has a great impact on individuals and organisations. Supported by teamwork the organisations could be more flexible and generate better responses to the challenge of a competitive business environment [7].

"(…) a team is defined as group of committed people with specific skills, abilities and interdependent roles who work together in an environment of trust, openness and co-operation towards achieving common goals." [16].

3.3 Reviews

3.3.1 Project Lifecycle and the associated reviews

3.3.1.1. Project Lifecycle

Despite the sequential logic of project phases, a project can evolve to the next phase before the end of the previous project phase and its related tasks. The decision of start the phase immediately following the current phase leads to induced risks that must be clearly identified to prevent any kind of slippages [22].

The stages of the project are so [22]:

- Phase 0 – Mission Analysis and Needs Identification

Generally, this is an activity conducted by the project initiator, the top level customers and end users or their representatives, and it concerns the needs identification and the mission analysis [22], [23]. In this phase, the management considers the full spectrum of acquisition approaches and decide, supported by all the background information available, which elements be bought off-the-shelf and which elements will be in-house designed and built [24]. From this step it is possible to obtain as outputs [22]:

1. Identification and characterization of the intended mission;
2. Its expression in terms of needs, expected performance and dependability and safety goals;
3. Assessment of operating constraints, focusing on physical and operational environment;
4. Identification of possible system concepts, featuring the degree of innovation and any critical aspect (on this step data from other projects is collected and stored as source of feedback);
5. Preliminary assessment of project management data.

From this analysis comes the phase 0 documentation and it ends with the execution of the Mission Definition Review (MDR), which is used to judge the readiness of the project to move into phase A [22], [23].

- Phase A – Feasibility

This phase acts like a complement of phase 0, where the refinement of the needs expressed before takes place, and results in finalizing the expression of needs and proposing solutions that allow to achieve the project aim [22]. The main purpose of this phase is to develop a credible mission/system architecture which complies with the project requirements and constraints, and ensures the maturity of the project's mission/system definitions and associated plans to allow the beginning of phase B, within available resources and acceptable risk [24].

This phase enables the process of responding to the needs by [22]:

1. Quantifying and characterizing the critical elements;
2. Evaluating the various possible system concepts, making the determination of all possibilities, characteristics and the criticality of certain elements;
3. Comparing the concepts against the needs, helping on determination of levels of uncertainty and risks;
4. Estimating the technical and industrial feasibility;
5. Identifying, for every considered solution, the all kind of constraints (costs, schedules, organization, utilization, production and disposal), as well as the estimated margins.

This phase activities connect with the phase 0 activities and may require the modifying of the definitions of the intended mission. At the end of phase A, the Preliminary Requirements Review (PRR) shall be executed, which allows the system concept selection and the establishment of the baselines of the functional specification associated [22].

- Phase B – Preliminary Definition

The formulation of this phase is composed by a set of iterative activities focused toward baselining the Project Plan, finishing the preliminary design, and ensuring the design is feasible (supported by the Systems Engineering activities) to approve the entrance on detailed definition [24]. At this stage of the project, the acquisition of long-lead items may be started to achieve the schedule commitments. The project documentation must be updated and addressed the elements that will support the decision-making, to allow the confirmation of the project, in particular, the expression of the need by its technical specifications [22].

The outputs from this phase of the project are [22], [23]:

1. Selection of technical solutions for the system concept selected in phase A;
2. Precise and coherent definition through all levels of the project, allowing the preparation of the elements of decision to begin the next phase (by refining the understanding of the technical feasibility factors evaluated);
3. Results from the System Requirements Review (performed at system level);

4. Product tree, which should contain the identification of "make or buy" alternatives and the products specifications;
5. Confirmation of the feasibility of the recommended solution, as well as the operation conditions;
6. Establishment of the baseline master schedule and the baseline cost at completion;
7. Risk assessment updated.

This phase has two associated reviews, one linked to the evolution of the phase (performed during the phase timeline) and the other linked to the end of the phase (which allow the project to evolve to phase C or not). This first one is the System Requirements Review (SRR) and the other one is the Preliminary Design Review (PDR) [23].

Note that *"the Preliminary Definition phase should result in selection, justification and confirmation of the solution retained for the development"* [22].

- Phase C – Detailed Definition

The implementation begins on this phase of the project lifecycle with the project team working in accordance with the project plans [24]. The scope and type of tasks undertaken during this phase must match the model philosophy as well as the verification approach defined [23].

This project phase allows [22]:

1. Detailed study about the previous chosen solution, and the production of representative elements, enabling the detailed definition of the system and its components;
2. Final decision about "make or buy" products;
3. Confirmation of the set-up, test and qualification conditions, and the beginning of the production and verification methods;
4. The starting of procurement and technology assessments or qualification;
5. The update of the Production Master File for the final version, enabling the production of the system;
6. The establishment of the interfaces and their alignment with the development configuration baseline, and apply control to their corresponding Interface Control Documents;
7. The preparation of phase E activities.

At the end of this phase, the Critical Design Review (CDR) it is performed and assessed if the project is ready to enter phase D [22].

- Phase D – Qualification and Production

The phase D closes the system development and opens the system production. At this stage of the project, all the relevant documentation must be updated and released [22]. In this phase, if needed, the project updates its external contributions (partnerships, acquisition plans, and others) to ensure the successful completion of the remaining project activities [24].

The phase comprises the following major tasks [23]:

1. Full qualification testing and associated verification tasks;
2. Production, assembly and test all the flight equipment's and related ground support;
3. Full scale tests on the interoperability between the space and ground segment;
4. Preparation of the acceptance data package.

To confirm and verify the technical conformity between the components and its technical requirements, as well as their reliable operability, ground qualification tests must be performed [22]. If these testing activities were successful, the project evolves to the Acceptance Review (AR), to confirm that all the previous topics referred before were executed and allowing the preparation of the utilization phase [22].

- Phase E – Utilization

The utilization phase is made by the launch campaign, the launch and in-flight acceptance of space elements (if needed), which means that this phase corresponds to operation and maintenance of the system, and gathering the targeted data. Normally divides itself in two small phases [22]:

a) Phase E-1, which is the overall testing of the system, and comprises the launch activities and in-flight qualification and acceptance, allowing the assessment and measurement of performance levels. At the end of this steps, the system is ready to run the first in-space test review;
b) Phase E-2, the actual utilization phase, must consider the technical events of operation and requests for improvements. To maintain the state of the system under control, periodically shall be done operations reviews, which feedback will contribute to improvements and has a benchmark for future similar projects.

During the execution of this phase, the most exhaustive on reviews matter, four review are associated to it: the Flight Readiness Review (FRR) which is performed prior to launch, the Launch Readiness Review (LRR) executed immediately before the launch, the Commissioning Result Review (CRR) performed after the on-orbit commissioning activities were complete, and the End-of-Life Review (ELR) which is performed after the mission became complete [23].

- Phase F – Disposal

The simplest phase, is characterized by covering all events since end-of-life till final disposal of the product. During the utilization phase of the system, specific steps are made to prepare the concrete system disposal (each system has its specific steps). At the end of the phase, all project inventory is reviewed to assess if has value for future works or must be discard [22]. Its major task is comprised to the implementation of the earlier prepared disposal plan [23].

3.3.1.2. Project reviews

“The basic principle applicable to reviews of all European space projects is that a thorough overall examination of the technical status of the project is performed at crucial steps, involving independent expertise.” [22].

In a project manager view, the reviews are classified as a major responsibility and a critical point in project, being then understood as major milestones. A well succeed review assesses all the documentation and so, can identify potential problems at an early stage, generating outputs that project manager can use to mitigate the encountered problems or delays [22].

Despite the idea that a review occurs at the end of a set of activities, not taking in account if the project schedule slips or not, it is recommendable that the review be planned and executed at a natural stage of the work performed, and when the information and documentation about the project were enough to start the next phase of the project with confidence [22].

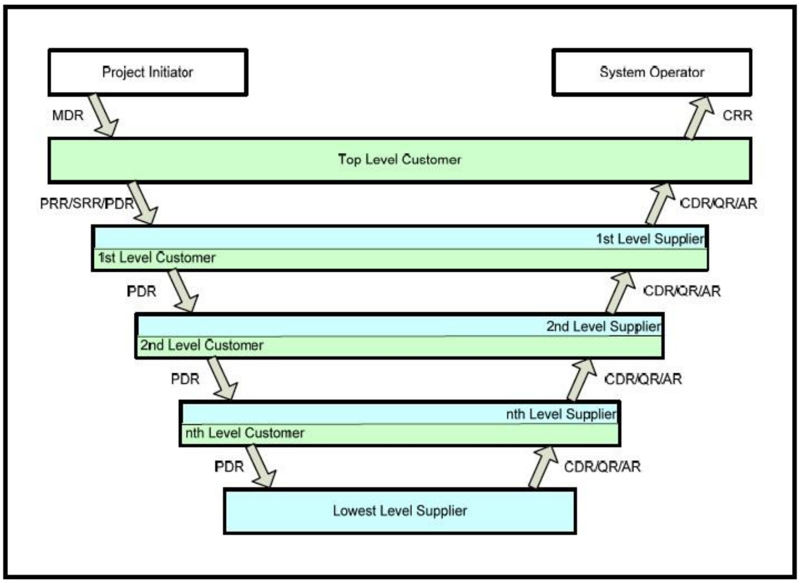


Figure 3.6 – Review lifecycle (adapted from [23])

The review team must belong to the decision-making authority, the supplier’s project team, among others, and they interact as defined in the following scheme:

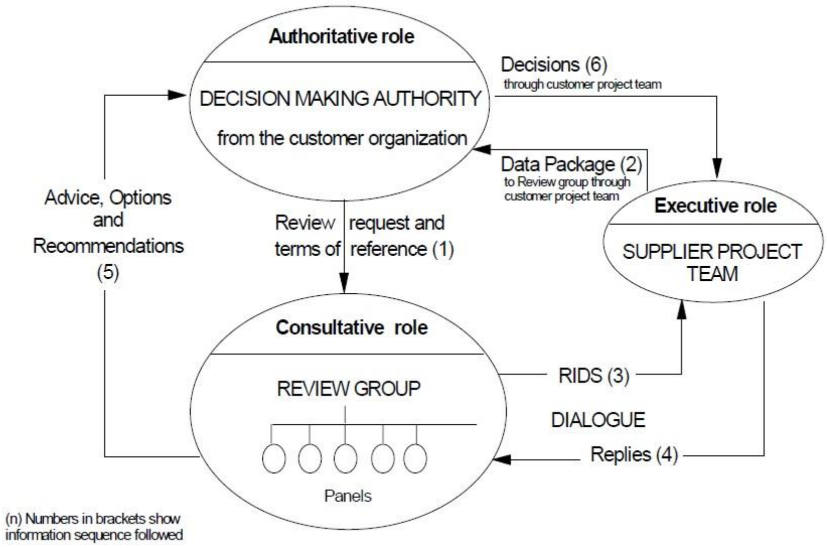


Figure 3.7 – Schematic presentation of interfaces and interactions between review participants (adapted from [26])

From all reviews referred by NASA and ESA, the following are the most important and the reviews that MECSE wants to perform, making it possible ensure the conformity of the project with the previously defined planning:

- Mission Definition Review (MDR) – the purpose of this review is to confirm that preliminary planning for project execution is flawless and to demonstrate that project is ready to evolve and continue with mission definition. To achieve that, the project exhibit an understanding of mission objectives and system requirements. It shows, even if preliminary, plan for prosperous execution of the entire lifecycle that is traceable and pragmatic in its resources estimates [27];
- System Requirements Review (SRR) – the steps that anticipate this review are the completion of establishment of system technical specifications, definition of the baseline master schedule done, the identification and definition of external interfaces, and the preliminary design definition [26]. On this stage, the main objective is essentially the assessment of preliminary design definition, simultaneously with the update and subsequent release of the technical requirements specifications [23];
- Preliminary Design Review (PDR) – at the PDR, the project unveils entirely the system design and warrant that it has completed a reliable and adequate mission formulation, is able to proceed with the detailed design (it exposes that the preliminary design meets all requirements with acceptable risk), about 10% of engineering drawings have been created, and is on track to conclude the flight and ground system development and mission operations to suit mission performance requirements within the determined cost and schedule constraints [11], [27];
- Critical Design Review (CDR) – the execution of this review pretends to demonstrate that the maturity of the design and development is appropriate to advocate proceeding with

full scale fabrication activities. At this phase the final detailed design (represented by complete drawings and analysis and supported by the results of breadboard and engineering model evaluation) must match the final performance and interface specifications, and the required design objectives [27];

- Qualification Review (QR) – this review is held after completion of the integration and test the qualification model and technical qualification of ground segment [26], and its purpose is to disclosing the complete and exhaustive project status to confirm readiness to execute environmental testing of the integrated flight system and to exhibit that the project is on track to fulfil the mission performance requirements, respecting the applied constraints [27].
- Acceptance Review (AR) – on this milestone, the project displays the results of its mission operations activities to prove that compliance with all requirements have been examined and that the capability to perform all phases and modes of mission operations, data processing and analysis have been shown [27]. The kick-off of this review is the conclusion of the integration and test of the first flight model to the flight design qualified [26].
- Flight Readiness Review (FRR) – at the time of FRR, all flight and ground system verification activities already have been successfully completed, ensuring that the system is ready for final preparations prior to launch [27]. To accurate execution of the review, the project needs to demonstrate that all performance and environmental verification activities of the integrated flight system have been completed with the expected results, that every ground system verifications and compatibility tests were well succeed, that all discrepancies have been solved, and that planning and preparation for the next (and remaining) activities of the project lifecycle have been finished [27].

3.3.2 Methods to perform a review

The reviews scheduled to be performed at the end of a certain project phase are the support to the decision if the project will advance to the next phase of if will be aborted. Therefore, all the information must be gathered and checked to ensure that is complete and that the right decision is made [28].

The review process must be performed rigorously and thoroughly to aid a successful subsystem development process, executing formal review processes considering review boards, action items, informal peer reviews and engineering design reviews to guarantee the premise [29]. These reviews outputs are used to minimize risk, identify uncertainties, assure technical integrity and assess alternative design and engineering approaches, mainly [30].

The principal elements that must integrate a review process to fulfil its purpose and deliver the proper outputs are [26]:

1. Timely definition of the data package;
2. Complete documentation related to the review objectives;
3. Precise identification and allocation of tasks to the review board;
4. Focus on reviewing the working documentation;
5. The assessment of the documentation by the review board must generate and present Review Item Discrepancies (RIDs);
6. Concise presentation by the contractor early in the review process, including answers to possible questions;
7. Consolidation of the inputs provided, followed by recommendations;
8. Project follow-up and confirmation of convenient closure of actions.

In way of conduct a good review, it must follow a certain method and measures (previously defined) and consult a large variety of sources to obtain an accurate appraisal about schedule, costs, and technical performance [30]. These data normally are delivered to external sources with knowledge in the subjects, which will assess the documentation and generate a feedback about it and about the further steps [28].

Due to specificity of a review, it is difficult to formulate a template which acts as a guide to execute it on any kind of project, but some basic principles adaptable for every review can be formulated [31]:

1. <u>The variation principle</u> – reviews have diverse purposes, and should be arranged and adapted to fulfil those purposes;
2. <u>The efficiency principle</u> – the efficiency of a review is the efficacy in achieving its purposes, related with the costs of its execution;
3. <u>The payoff principle</u> – the compensation to the project for doing a review is a function of losses that could happen if the review weren’t performed, and the absence of improving actions;
4. <u>The many-purpose principle</u> – a specific review could itself have multiple concurrent purposes, and each objective needs to be undertaken in designing that review;
5. <u>The manifold principle</u> – a given review might aspire to deploy a large number of phases, and a large amount of tactics, to provide the best efficiency;
6. <u>The “prevent, don’t clean” principle</u> – the review process shouldn’t have the “task” of clean up bad work, but they should be used to measure the quality of delivered work, and to motivate professionals to deliver work up to standard;
7. <u>The teaching principle</u> – an educational mean could be addressed to the reviews, if they’re used to instil into people the specific (corporate) engineering standards, usually with best adherence and more effective than formal training can;

8. The stitch in time principle – the reviews should contain a number of internal devices to allow the review management to stop the process or downsize it, when it obviously will be a waste of time to continue;
9. The entry-exit principle – a review should be properly conducted by formal process entry and exit conditions;
10. The clean to be mean principle – specifications need to be “polish” before they can be meaningful to project’s aims. This means that is impossible to judge if specifications fit their purpose if they aren’t clearly written yet.

Whenever a problem appears at any review, an action plan is defined to thwart it, and if the problem requires further investigation, a person is assigned to summon another meeting as early as possible and elaborate an action plan, which should contain a description of the problem, steps to fix it and the necessary actions that should be taken. To ensure accordance with other plans, the project manager (or the person responsible) should inquire every part who will contribute or be affected by the action plan [30].

“Every review is a chance to see how well the project is carried out and where room for improvement exists” [28].

3.4 Communication

As part of the project plan the project manager should address a communication plan which contemplates all forms of communicate between all intervenient of the project, such as formal and informal, verbal and written [30].

Most of the communication in organisations and projects happens informally, which has its deficiencies and does not guarantee that the final consignee will ever get it. Notwithstanding, it is widely beneficial and essential, because it fulfils social and work needs, and transmits information faster and directly than most formal systems [30].

Despite managers cannot control this type of communication, they can arouse it by insisting on informality, removing status barriers and inspiring casual conversations between everybody in the task force, or by getting managers out of the office, talking to lower level workers [30].

3.4.1 Communication channels

Communication channels play an important role in creating an atmosphere for successful implementation. Today's tools such as desktop and video conferencing, and file sharing of technical data allows the exchange of information quicker and more efficient, increasing communication power, which can be very useful if correctly used [7], [29].

The commonly channels used are the following [32]:

- E-mail;
- Consortium meetings;
- WP leaders' meetings;
- Video conferencing;
- Teleconferencing;
- Restricted partner area on the project's website.

3.4.2 Communication principles

The purpose of communication principles it is to help the project team improving the communication among all the parties involved, identify stakeholders, and develop an efficient communication plan. Effective communication can be built from a combination of selected methods and tools, which should be chosen at project management level. These methods and tools will guide the members towards coherent communication through whole project lifetime [32].

The actors in charged for communication planning should specify who needs the information, when they need it, who will deliver it and how it should be delivered [32]. This person should also ensure a conscientious team effort to communicate clearly (this is one of the most powerful ways to achieve mission success) [29].

The communication between the actors should be both vertical and horizontal, which means that communication should exist up and down hierarchies as well as between units at the same hierarchic level. This approach is gaining more prominence since teams are becoming more temporary and projects use more external sources for achieving goals [33].

3.4.3 Conclusion

"(…) effective project communication takes many forms in various venues to many different stakeholders. It is the cornerstone on which projects are built. Projects with effective communication are much more likely to succeed than those that lack a consistent and appropriate means of communicating across the team and stakeholders. Timely information delivered in the proper way is empowering to all who receive it. Finding the right balance of level of detail and

frequency of information communicated across the project is the job of the project manager and it is one of the most important ones" [29].

This quote gathers all the most important aspects of a good communication and all the team should take this in mind while performing their role in some project.

3.5 Management planning

3.5.1 Project formulation

Project is a singular effort with a defined beginning and an end, having clear-cut goals, cost, schedule and quality, and employ limited resources to achieve defined objectives [34].

Most of the projects require formal, detailed planning, due to their short duration and often emphasises on control of resources. The integration of the planning activities became necessary because each work sub-team may develop its own planning documentation without concerning about the other sub-teams [18].

At the early beginning, it is necessary to define the purpose and the objectives of the project, which includes key performance parameters and technical and programmatic constraints to be applied to the project [23]. The first step after setting the above conditions is the strategic acquisition process, providing to management a full acquisition approach for project, allowing the decision for select commercial off-the-shelf buys or in-house design and build efforts [24]. Moreover, the project should be defined from the earliest days in terms of ownership, cost (range), duration and phasing, marketing and sales, organisation, energy and raw materials supply, and transportation, avoiding the skip of key issues essential to its viability [7].

"No design is ever complete; technology is always progressing. A central challenge in the effective management of projects is thus the conflict between meeting the schedule and the desire to get the technical base that fits better" [7].

As the project matures, the project plan is revised and the new data are added. A certain degree of change and uncertainty is implicit in engineering, and so changes in plan are expected, becoming essential that it can be updated quickly and regularly to remain a guide to the most efficient way of achieving the well succeed completion of the project [33].

3.5.2 Project Management planning and tools

The initiation of the planning is a responsibility of the project manager, after the upper approval. He gathers the team and conduct planning sessions to create a statement of work that outlines the customer requirements [7].

An effective scope statement should include a project name, date, the project manager's name, project justification, product description, deliverable/milestones, objectives, assumptions, constraints, any issue or risks, who wrote the statement and the date it was written, and the approval with a date [7].

Monitoring and controlling the project execution helps the project manager to proactively know if some potential problems are arisen, allowing the initiation of corrective actions, avoiding a crisis. This task becomes especially important because it has the potential of reduce the resources consumption on this project phase. Monitoring also helps assessing the project's real performance against projected performance [7].

Product development involves generation of ideas, product design, and detailed engineering. Before the production process the project must pass through a development process which can involve hundreds of activities. These activities are directly related to the project complexity, being much more has more complex the project is, increasing the relations between activities and therefore the project becomes more complicated. One way to interpret the project in simple terms is using diagrammatical project management techniques such as networking techniques (PERT- Program Evaluation and Review Technique and CPM- Critical Path Method), Gantt charts, breakdown structures, organisational charts and others. While Gantt charts provides a way to manage and control time and resources, network techniques provide a way to manage project activities by identifying their relationships and precedencies [35], [36].

The project management focuses on developing feasibility studies and in advance analysis to generate an appropriate strategy, governance and delivery structure. The right tools should be selected to support success and guarantee the necessary control over the project [32].

Some of the most common tools used by project managers are Microsoft Project©, Primavera©, Open Plan©, and ProjectLibre© (used within the framework of the schedule management) [29].

Due to projects complexity, other tools and methods are applied simultaneously, such as some of the following list [32], [33], [37]:

- Bar charts;
- The Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT);
- System Dynamics Method (SD);

- Design Structure Matrix (DSM);
- Earned Value Management (EVM);
- Combined Project-Project Model-Based Plan;
- Critical Chain Project Management (CCPM).

3.5.3 Tailoring

Tailoring is the process used to modify the requirements to accommodate the specific needs of a task or activity, being an expected and accepted part of setting the proper requirements for the project and, with a formalized and disciplined approach, in the exact time and with proper feedback, will improve the prescribed requirements [24].

This process allows projects to execute only the activities that are needed for mission success without compromising external requirements, considering lessons learned and best practices. Project managers should thoughtfully examine and tailor the requirements so the final project requirements will be only those that contribute to achieve mission success [24].

To perform the tailoring process, the project manager uses knowledge and skills to evaluate every requirement and to tailor each one as much as needed, ensuring that the competing demands of scope, time, cost, and quality are undertaken to fulfil those demands [7].

"The tailoring of project methodology provides an adequate level of control to guarantee the achievement of a successful project" [32].

3.5.4 Project baselines

The established project baselines acts as a reference by which the project manager can manage and oversee the project and then measure and compare the future performance and states. This baselines consists of an agreed-to determined requirements, technical content, WBSs, costs (including all unallocated future expenses), schedule and, sometimes, other resources such as workforce and infrastructure [24].

Replanning and rebaselining are differentiated by the magnitude of the changes in cost parameters, mainly in the project's development cost, and by the project's lifecycle phase at the time the increased costs is identified. Replanning can occur at any lifecycle phase while rebaselining occurs only during the implementation phase. The need to rebaseline is an atypical situation. The managers should monitor and control frequently the scope and performance to be able to apply corrective actions when the project is running out of the estimated costs [24].

3.5.5 Work Breakdown Structure

The first considerable step in the planning process after project requirements definition is the development of the Work Breakdown Structure (WBS), which is a product-oriented family tree subdivision of the overall project goals into specific activities or tasks for each subsystem or component. It also provides a framework for managing cost, schedule and technical content [11], [23], [24].

The WBS is organised in accordance with the flow of the work and reflects the way in which project costs and data will be collected and reported [18]. A set of conditions should be considered when the WBS is being developed, such as [29]:

- The level the customer expects costs will be reported;
- How the contractor's financial system agglomerate costs;
- How costs might be stratified;
- The level required by the technical management should match the required customer reporting level;
- The acquisition of costs should facilitate future similar efforts.

"The Work Breakdown Structure acts as a vehicle for breaking the work down into smaller elements, thus providing a greater probability that every major and minor activity will be accounted for" [18].

3.5.6 Methods to perform a change on the project scope

Almost no project is ever completed according to the original plan. On the origin of the project changes are the increasing of knowledge, a need for competitiveness, or changes on costumer tastes [18].

Projects have a natural propensity to grow over time because of changes and additions in the scope, a phenomenon called "scope creep". These changes or additions occur motivated by changes in requirements and work definition, provoking almost always an increase in the budget and/or schedule [30].

Generally, the bigger and more complex the project, more required changes will occur on the original project plan. Besides the cost and schedule overruns, even workers' morale and the relationship between contractors and clients will be affected. Each change has a ripple effect, which means that one change can generate an uncontrolled chain reaction and other subsystems or components and so on. Rarely does a change occur in isolation [30].

Sometimes design changes in one subsystem or component cannot be avoided, and this leads the project to redesign the interrelated subsystems and components. These design changes made during fabrication and testing drive to huge increasing in project cost and duration [30].

3.6 Schedule management

3.6.1 Schedule management plan

The management of time in the design phases is crucial to meet the expected delivery date of the project and allows the adherence of the project schedule [33].

Schedule management plan is the process of set up the policies, procedures, and documentation essential for planning, developing, managing, executing, and controlling the project schedule. Performing this process helps providing guidance and direction on how the project schedule should be managed throughout its duration [14].

3.6.2 Project time management

3.6.2.1. Defining activities

The definition of activities is a process of identification and documentation of the specific actions to be executed to produce the project deliverables. To perform this process, it is required a clear understanding of the activities outlined in the WBS. This will become important to identify the interdependencies among activities and the type of resources needed to perform each activity. At this stage it is important not to focus too much on dates, the important focus should be on finding out what the team believes that are the necessary tasks required for project completion [7], [14].

On this step it is important to be cautious about identifying tasks to avoid too broad tasks in scope, the goal is understanding what must be done and how it ties into other activities [7].

The inputs combined with the tools and techniques generate the following outputs [14]:

- Activity list – this is a comprehensive list that includes all schedule activities required to project completion. This list also includes the activity identifier and a scope of work description for all the activities in sufficient detail to ensure the understanding of the required work for each activity completion by all team members;
- Activity attributes – it extends the description of the activity by identifying the components associated with each one of them. This can be used to identify the person responsible for executing the work, the place where it was performed, the activity type and others. The activity attributes even allow the schedule development, the selecting, ordering and sorting the planned schedule activities;

- Milestone list – this is a list where are identified all project milestones and indicated whether the milestone is mandatory or optional.

3.6.2.2. Sequencing the activities

After the development and understanding of all activities needed to be done to fulfil the project objectives, the next step is understanding the dependencies between the activities. A network diagram visually displays how the work in project comes together and will help to flesh out the relationships among tasks within a team and dependencies of work between teams [7].

At this phase a balance between details and risks of too much detailed documentation should be considered, being recommended to base the amount of detail on the complexity and length of the project [7].

A key consideration is that all activities or milestones, except the first and the last activity, should be connected to at least one predecessor. These relationships should be designed to create a realistic project schedule and may be necessary to use lead or lag time between activities to achieve it [14].

The inputs combined with the tools and techniques generate the following outputs [14]:

- Project schedule network diagrams;
- Project documents update.

3.6.2.3. Estimating activities resources

A plan cannot be created without considering the people who makes the team. For each defined activity, the project manager should understand the type and quantity of each skill set required. Despite the initial consideration being connected to the team, the materials, equipment, and suppliers should also be considered. All these together allows more accurate cost and duration estimates for the project [7], [14].

Sometimes, it is necessary to assign a resource without fully knowing the details behind the activity, but the resource should be assigned anyway. Someone must be responsible for every activity [7].

"Do not take estimate activity resources lightly, as not digging in and understanding the constraints and availability of your resources can have serious repercussions on the timeline that may not become known until it is too late" [7].

The inputs combined with the tools and techniques generate the following outputs [14]:

- Activity resource requirements;
- Resource breakdown structure;
- Project documents update.

3.6.2.4. Estimating duration of activities

At this step, the timeline that results from planning can already be seen. An important consideration to have present at this stage is the distinction between “duration” and “effort” because it will influence the duration of each activity [7].

To estimate activities duration is not a one-time task, instead it should be iterative at key points in the project. This means that as the knowledge about the project evolves and how the activities could be done, the estimates can be refined, producing a more accurate timeline [7].

An important task to project manager at this phase is ensuring the correct storage of all the documentation used in this process. This documentation will help later the understanding of some decision made and will help in further refinements to estimations [7].

The inputs combined with the tools and techniques generate the following outputs [14]:

- Activity duration estimates;
- Project documents update.

3.6.2.5. Developing the schedule

Finished the previous four steps, all the activities are defined and all predecessors and successors are documented, a resource calendar is made and the proper duration for each activity is allocated, is now possible to create the schedule baseline, which should be updated and refined throughout the project [7].

The construction of the schedule should start by external and internal milestones inasmuch as all activities should support these milestones. Then, a proper summary level tasks should be careful done, rather by subsystem, even if it does not flow chronologically (easier for each team find their assigned tasks) [7].

The following work consists on the application of time constraints documented before, not forgetting the lead and lag constraints, creating a dynamic plan which will change during the project lifecycle, as a reflection of the real time spent until each task is complete [7].

The inputs combined with the tools and techniques generate the following outputs [14]:

- Schedule baseline;
- Project schedule;
- Schedule data;
- Project calendars;
- Project management plan updates;
- Project documents update.

"Congratulations: you now have a project schedule. Review it once more with the team to get buy-in on the schedule baseline, as this is foundation for Project Tracking and Oversight" [7].

3.6.2.6. Controlling the schedule

Control schedule consists on monitoring the status of project activities to update the project progress and manage changes to the schedule baseline to accomplish the plan. To avoid slips it is recommended to project manager to ask frequently the status of each activity, to have a whole comprehension about what is done and what is missing to complete the activity, and ensure that the team tries to respect the baselined end dates [7], [14].

Control schedule is one of the most important roles in project. The project manager should be always alert for areas in the plan that still require refinement, and be prepared to take immediate corrective actions when schedule slips [7].

The inputs combined with the tools and techniques generate the following outputs [14]:

- Work performance information;
- Schedule forecasts;
- Change requests;
- Project management plan update;
- Project documents update;
- Organisational process assets update.

3.6.3 Milestones

A milestone list identifies all project milestones and indicates whether the milestone is mandatory or optional. The biggest difference between a milestone list and regular schedule activities is that the milestones are identified on the schedule by tasks which the duration is zero days because they represent a moment in time [14].

Milestone schedules are simple lists of top-level events with planned dates, and are included in the project management plan. These same lists are used for reporting schedule progress by adding a column for completion date information. Any planning drawn up should be linked to the WBS such that per each project phase all the major project milestones can be identified [7], [38].

The list of milestones can be derived from all the planning data gathered by computerised methodologies which creates a logical time sequence. From this list, some milestones are selected for schedule control purposes [38].

3.6.4 Critical path

The critical path is the contiguous path of tasks in a schedule that represents the longest path through a project, which defines the shortest possible project duration. The critical path is the “longest road” in the schedule with the least amount of total slack (total slack is the amount of time a task’s finish date can be delayed without causing delays on project finish date - is called total float too). Meanwhile, the critical path does not have necessarily 0 of total slack [14], [29].

A CPM critical path is usually characterised by zero total slack on the critical path, but it can show positive, negative and zero values depending on constraints applied. Positive total float is observed when the backward pass is calculated form a schedule constraint that occur later than the early finish date that has been determined during forward pass determination, and negative total float is observed when a constraint on the late dates is violated by duration and logic [14].

3.6.5 Technology Readiness Level

Once the cost estimations are complete, the next step is to consider the risk associated with the design tasks. If technology is mature, and there is great experience and knowledge in the design, the risk could be low however, if the technology is new, or the designers have lack of experience with the technology, the risk is high [33].

To determine the level of the risks associated is frequently used the technology readiness level scale, which is a description of the performance history of a given system, subsystem, or component relative to a set of levels. Its range is from TRL 1, basic technology research, to TRL 9, systems test, launch, and operations, being the key point at TRL 6, which is usually the minimum required to integrate a component in a flight system [11], [24].

Figure 3.8 displays the criteria to assess the TRL used by NASA, and adapted by ESA.

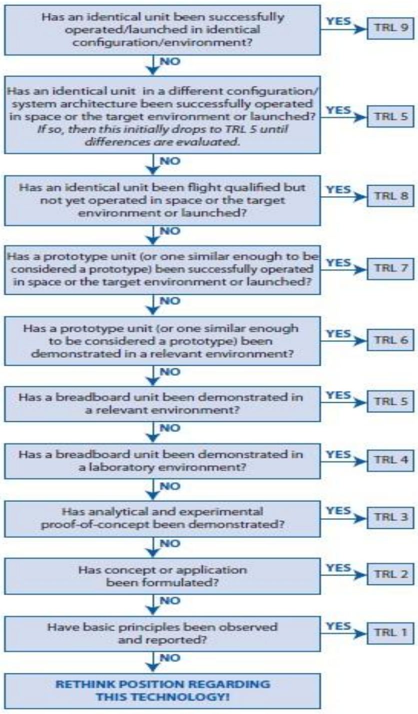


Figure 3. 8 – Technology Maturity Assessment (TMA) chain process (adapted from [11]).

Defining the TRL is an essential kickoff to a successful project. A frequent misconception is that in practice it is too difficult to determine TRL. A crucial factor to take into account is that the TRL of a system is determined by the lowest TRL present in the system, which means that a system is at TRL 2 if any component of the system is at TRL 2, and all of the elements can be at a higher TRL. However, if they have never been integrated as a unit, the TRL of the unit will be at a lower level (how much lower depends on the complexity of the integration) [11].

The assessment of the TRL's assumes an important role on space projects. The TRL's are indicators of which technology is already enough developed for the purposes of the project and which technology must be upgraded. Figure 3.9 displays the description of each level of the TRL scale for space projects [11].

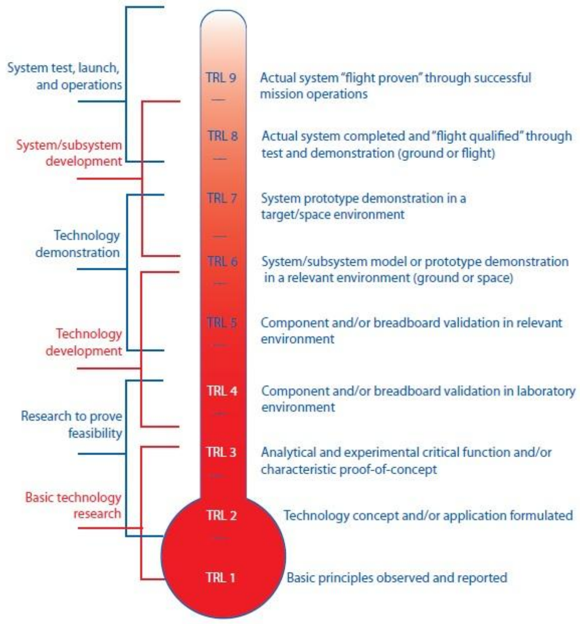


Figure 3.9 – Technology Readiness Level (TRL) (adapted from [11]).

3.7 Risks management

3.7.1 Introduction

Risks management is applied by project managers to identify, evaluate, prioritize, and mitigate negative events before they become problems. Risks are potential problems that are managed in an attempt of lowering the probability of occurrence, in contrast problems are adverse events that have already occurred and must be dealt with. Risk management is extremely important on spaceflight missions where cost, schedule, and technical margins are highly constrained [29].

One of the most important aspects of risk management is the communication. If the team communicate between them potential problems, all can work toward a common goal [29].

Defining a method for applying risks management to CubeSats will result in more informed decision making, increasing the chances of a more successful spacecraft missions [39].

A risk management plan should perform three major steps, and each one of them embraces some sub-steps, as detailed in the Figure 3.10 [39]:

Main Step	Sub-steps
A. Risk identification	1 Review the mission concept of operations 2. Identify root causes 3. Classify priority of risk 4. Name responsible person 5. Rank likelihood (L) and consequence (C) of root cause 6. Describe rationale for ranking 7. Compute mission risk likelihood and consequence values 8. Plot mission risks on L-C chart
B. Determine mitigation techniques	Choices consist of: 1. Avoid the risk by eliminating root cause and/or consequence 2. Control the cause or consequence 3. Transfer the risk to a different person or project 4. Assume the risk and continue in development
C. Track progress	Plot the mission risk values on an L-C chart at key life cycle or design milestones to see progress.

Figure 3.10 – Steps and sub-steps for risk management (adapted from [39]).

3.7.2 Types of risks

Mission's risks are higher-level failures, and they are caused by failures at system-, subsystem-, and component-level. These risks are a scenario that jeopardizes the likelihood of project success and focuses on the areas of cost, schedule, technical, safety, or programmatics (many of them will impact multiple areas) [29], [39].

Risks are classified in the category that would be impacted most directly in the project, when they do not have a mitigation plan, and those categories are [29]:

- Inherent to project concept;
- Technical;
- Cost;
- Schedule;
- Safety;
- Programmatic risks.

3.7.3 Risks management tools

There are many tools which helps the project manager on developing an accurate and powerful risks management plan. According to [29], [39], some of most important tools to perform this task are:

- The team;
- Risks meeting;

- Risks evaluation;
- Likelihood-Consequence (L-C) rank.

The team, gathered in a risks meeting, may perform a brainstorm session to assess all project risks associated to each subsystem or component, preventing eventual gaps where the assessment is being done. Thus, becomes crucial evaluate those risks and generate the L-C rank, which will allow to define the risks mitigation priorities for the project [39].

3.7.4 Mitigation plans

The direction to take for project risks is the development of an adequate mitigation plan and then implement it, and perform assessments to evaluate if the risk is mitigated. The best solution for mitigation of risks is based on the selection of the option that provides a better balance between performance and cost [29], [39].

The risk mitigation can be accomplished by four different ways, which are [39]:

1. Avoid risk by eliminating the root cause and/or consequence;
2. Control the cause or consequence;
3. Assume the risk and continue in development.

It is recommended to have at least one mitigation strategy for each risk and their root causes, but as more mitigation strategies the risk has, less likelihood and consequences it would create upon the project. The mitigation strategies should mature as the project matures [39].

3.7.5 Risks mitigation actions

After performing risks assessments, the project manager delegates in a team member to be responsible for the risk. That team member becomes the responsible for managing those risks, which involves further characterisation or research into the risk, refinement of mitigation strategy, tracking and updating the risk, and reporting to upper management its status [39].

The status of risks is tracked by assigning of one of the following three characterisation options [39]:

1. Research - this option is used when an analysis for better understanding of the risk is required, or the risk mitigation plan is under development. This option should include the establishment of a deadline for completion;
2. Watch - this option suggests that the team member responsible for the risk continues to monitor the risk, looking for changes in the likelihood and/or potential impact of the risk. This option determines that significant variations on risk severity (positive or negative) should be properly reported to upper management for re-evaluation of the risk;

3. Mitigate - this status is used when a contingency plan is initiated. As soon as the risk meets the contingency plan closure criteria, the risk item can be closed. If the risk remains at lower levels of L-C ranking, the project manager (or upper management) can decide if is necessary to continue monitoring the risk or if project accepts the residual risk.

3.8 Documentation and data management

The technical data management process is a tool to plan for acquire, access, manage, protect, and use data of a technical nature to support the total lifecycle of a system. Its objectives are providing useful and essential information to internal and external actors involved in the project. Data management also includes the development, deployment, operations and support, eventual retirement, and retention of appropriate technical data beyond system retirement [11], [40].

3.8.1 Policies and principles

Each project decides data needs during lifecycle, which may be defined in standard documents. Sometimes, the contractor's organisational directives specify the content of documents that should be followed for in-house data preparations [11].

The most important principle ruling data management is that the tool/ technique employed to perform this management should be the least complex which is capable of fulfil the project information processing, control, distribution and archiving requirements [40].

3.8.2 Data management plan

A data management plan (DMP) is a formal document that covers the major data management topics, such as identification of data requirements for the overall project lifecycle, control procedures, guidance on how to access data for users, data rights and distribution limitations, and storage and maintenance of data [11].

The planning for data management consists on [11]:

1. Preparing the technical data management strategy, which can document how the project data management plan will be executed;
2. Obtaining a strategy/ plan commitment from relevant stakeholders (UBI and CEiiA in this particular case);
3. Preparing the implementation procedures;
4. Defining a database to use for technical data maintenance and storage;
5. Defining the tool employed on data collecting, proper adapted to the data management pretended and resource consumption estimated;

6. Establishing electronic data exchange interfaces according with international standards and agreements made;
7. Training stakeholders and team members in the established technical data management plan, procedures, and data collection tools.

The elements that should be present on a Data Management Plan are [41]:

- Data description – description of the information to be collected;
- Existing data – search about other projects relevant information and determination of whether and how these data will be integrated;
- Format – format decided to generate, maintain, and made data available, justifying the choices made;
- Metadata – description of the generated data, which normally includes who, what, when, where, why, and how about the collected data;
- Storage and backup – procedures adopted for storage and backup data, including the facilities and virtual resources used for its preservation;
- Access and sharing – description of the data protection procedures, its potential secondary users, as well as how this data will be shared, how much time it will be retained on source, and technical mechanisms for dissemination followed by who can access these data;
- Responsibility – individuals responsible for data management in the project;
- Intellectual property rights – entities or people who will hold the intellectual property rights to the data, noting any copyright constraints;
- Selection and retention periods – description of how data will be selected for archiving, how long it will be confidential, and plans for transition or termination of the data collection in the future;
- Budget – costs related to data preparation for archiving and how these costs will be paid. If a request for funding is necessary, it may be included;
- Data organisation – description of how the data will be managed during the project, containing information about versions and naming convention;
- Quality assurance – procedures adopted for ensure the data quality.

3.8.3 Lessons learned

Lessons can be learned from every project, even if the project is a failure, lessons can still be acquired from it. They are important to future projects because they show hypotheses and conclusive insights from previous projects. Sometimes it is difficult to document lessons learned because employees are reluctant to sign their names to documents that indicate they made mistakes, not avoiding this way that other employees does not made the same errors [11], [18].

Capturing lessons learned is a function of good management practice and discipline. Many times, lessons are missed due they should have been developed and managed within or between lifecycle phases and it is frequent to wait until resolution of a situation to document a lesson learned and later it is harder to recreate the mishap [11].

The most common lessons learned acquired by the management of projects are [7]:

- Do not miss any of the stages of the project;
- Use known technology as far as possible (avoid unnecessary innovation);
- Test technology before committing to production;
- Avoid making technical or design changes once implementation has begun;
- Order long-lead items early.

For better lessons learned gathering, some directives should be accounted, which are [17]:

1. <u>Select the participants</u> – carefully chosen who is best placed to draw out the lessons learned, ensuring that a balanced cross-section and open minds exists;
2. <u>Confirm the audience</u> – clearly identification of the lessons learned receiver;
3. <u>Identify success and failure</u> – the lessons learned are not only about what happened bad, is also about what was performed well;
4. <u>Develop the lessons to be learned</u> – clearly identify the reasons why events went that way. Register the actions made and possible different actions which could bring other results;
5. <u>Document and review the lessons learned</u> – a summarised written lesson learned should be drawn at this point, ensuring that everything was described accurately.

And those lessons learned should emphasises on [17]:

- Lessons must contain specific, realistic, practical pieces of advice;
- Lessons must conclude with recommended positive actions;
- Lessons must be free from references to individuals.

"A lesson learned is attempting to run a project without a plan is like trying to travel to a destination via an unknown route using a map, while having no current location and no indication of a direction to take. Therefore, a map is a useless tool in this instance" [7].

3.9 Conclusion note

The objective of this entire chapter was highlighting the project management fields of work specifically for MECSE project. These are not all the fields of PM, instead are those considered priorities for implementation due to the stage of the project.

This chapter acts as a support for the implementation process defined for MECSE project and which will be explained in the forward chapter. The scheme of the chapter 4 – Project Management Implementation is organised to follow the same order defined for chapter 3 – State of the Art.

Chapter 4 - Project Management Implementation

The Project Management (PM) methodologies described in this dissertation were implemented on MECSE between May and October 2017. The MECSE documentation can be fully conferred on Annexes of this document.

This chapter begins with a brief description the MECSE project, and further provides to the reader a vision about the methodologies implemented by the author. The methodologies already implemented at the time of the conclusion of this dissertation are: the team building and team organisational scheme; a formal definition for the communication methods and channels; guidelines for management planning such as the approval flows and the project preliminary estimations; a schedule management process supported by appropriate software; a risks assessment and their proper management approach; and documentation and data management guidelines.

At the end of the chapter is shown a current status of the project related to each subsystem. The purpose of this status is to highlight the tasks already performed by the team and the further tasks required to the desired project objectives.

4.1 MECSE description

MECSE – "MagnetoHydroDynamics/ ElectroHydroDynamics CubeSat Experiment" is an exploratory research & development project addressing an emergent research topic within the Space Science and Technology field, integrated in the Azores International Research (AIR) Centre initiative.

The project proposes an exploratory approach targeting the feasibility study and preliminary design of a nanosatellite based on a standardized modular platform (CubeSat) whose main purpose is to create a benchmark for the future test of the theory that an *"electromagnetic field (ExB) can thin down a layer of plasma and therefore allow communications during the atmospheric re-entry blackout phase"*.

To achieve this goal a CubeSat shall orbit the Earth gathering data on plasma, and performing tests on signal loss/gain using an ExB control for the plasma layer. The mitigation of radio blackout during atmospheric re-entry is a crucial requirement in the design of space vehicles, considering safety and accomplishment of manned and unmanned space missions [9].

In re-entry vehicles, or when a satellite approaches Earth, radio waves are blocked and reflected due to an increase of electron density in the weakly ionized plasma layer, which is created around the vehicle surface during hypersonic flight. Such an increase of electrons will lead to a rise in plasma frequency that will exceed the frequency range of conventional band communication signals.

MECSE is a three unit CubeSat, having four kilograms, developed by a partnership led by University of Beira Interior (UBI) and CEiiA. As a CubeSat, it must fulfil the CubeSat Design Specifications, so it has massive volume and mass restrictions.

In May 2017, the engineering team working on MECSE was composed by twelve students and six senior researchers, students are from UBI and senior researchers are three from UBI and three from CEiiA. All the students participate in full time study programmes, and contribute to the project development on a voluntary basis.

4.2 PM methodologies implementation

4.2.1 Team building

The concept of MECSE is mainly an academic experiment whose aim is to provide knowledge and know-how on projects and space projects, the human resources allocated are students performing their M. Sc. Dissertation on UBI, supported by experts from CEiiA. This cooperation between academia and industry is represented on the Figure 4.1.

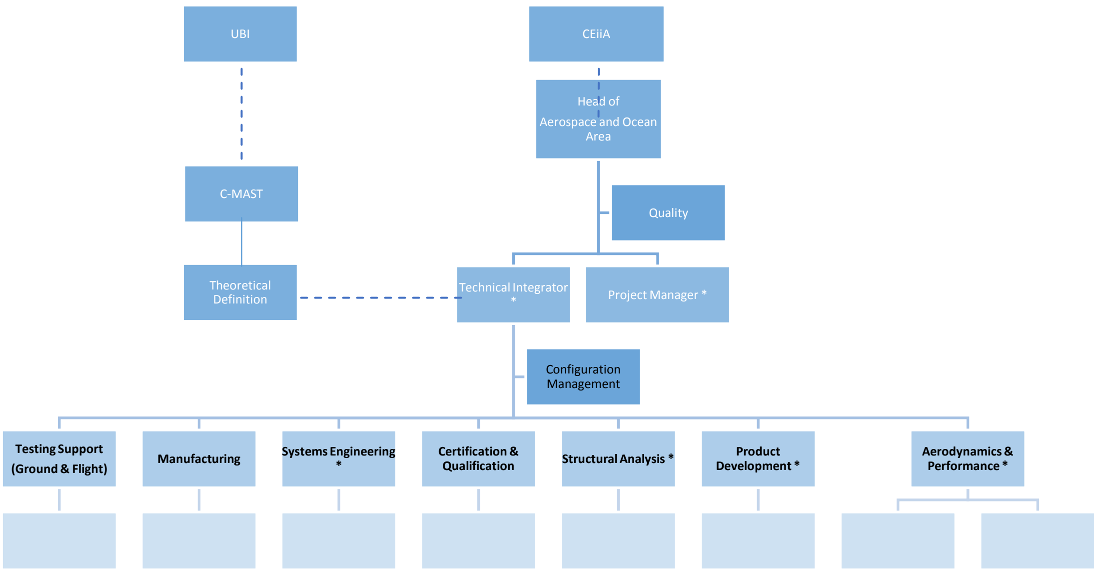


Figure 4.1 Project organisation by function/ task.

It is important to refer that the sub-teams represented with a (*) are the effective team members working at CEiiA's facilities, since the scientific part is being performed at UBI's facilities, where the aim is to validating the payload properties, focusing on the electromagnetic field needed to fulfil the research objectives during the MECSE mission.

The current project organisation does not have a Quality manager, a Certification & Qualification team, a Manufacturing team, nor Testing Support on the team since the project is running the preliminary design phase.

The mentor engineers at CEiiA are represented by the block called "Head of Ocean and Space Unit", currently being focused on supervising the preliminary design of the satellite structure, the preliminary payload design, the mission analysis and the management of the project.

4.2.2 Project communication

The communication plan implemented on MECSE project is very simple and contemplates the communication between the team members allocated at CEiiA's facilities, the team members working at UBI's facilities, and the engineers.

The MECSE project communication plan, describing the various types of communication and its specifications are represented in Figure 4.2.

Communication Plan				
Type of communication	Periodicity	Location	Attendance	Meeting Objectives
Daily meeting	Every day	At the office	The team members working at CEiiA's facilities	Quick project status update
Weekly meeting	Every Friday at 12:00	On an appropriated room for the event	The team members working at CEiiA's facilities	Update about the work week and establishment of the future work
Monthly meeting	On the first Monday of the month	On an appropriated room for the event	The team members working at CEiiA's facilities plus the team members working at UBI's facilities	Complete update about the project status, including the challenges faced and possible solutions
E-mail reports	Every month		From team members working at UBI's facilities to PM	

Figure 4.2 MECSE project communication management plan.

The informal communication as casual conversation between the participants while performing their own tasks are also relevant to the project evolution. Due to its characteristics, it is more difficult to predict the frequency and report the conversation content. However, it is assumed as a powerful tool and should not be ignored by the team.

The informal communication should be encouraged by project manager, and implemented as an open way to discuss the difficulties and unknowns that each team members finds during the project.

Concurrent Engineering (CE) is also an extremely important and strong tool available to accelerate the lifecycle of the project, by a better integration of activities and processes. This tool allows parallel work from different subsystems, generating consensus and getting decision made with the commitment to them from every part.

During the formulation of this dissertation, one CE meeting has taken place, at CEiiA's facilities, on 21st June 2017 and it was described by the following order:

1º Description of people involved;
2º Description of meeting objectives;
3º Meeting agenda;
4º Procedures for the meeting;
5º Adopted solutions;
6º Conclusions.

The result of the CE meeting is presented as an answer to each topic of the previous list presented before:

1º The people involved on the meeting was: prof. Anna Guerman, prof. Pedro Gamboa, Eng. Tiago Rebelo, Eng. Paulo Figueiredo, Eng. André João, Filipe Dias, Luís Estanqueiro, Eduardo Pinho, Luís Correia, Ana Azevedo, Jorge Monteiro, Gonçalo Pardal, Michael Arrington, Bradley Walcher, and Paulo Ferreira;
2º The meeting objectives were to synchronising the team members, update the status point about the critical areas of the project, to evaluate the priority of the next project steps to meet the schedule and costs estimation, and discuss the team doubts and unknowns related to current and further work;
3º The meeting agenda was:
   - Reception of the team members working at UBI's facilities;
   - Summarized presentation from each team member about the specific work performed;
   - Presentation of doubts and clarifications;
   - Constructive discussion about the further steps and possible changes to the project current development;
   - MDR meeting.
4º The CE meeting started with individual presentations from each team member, followed by a quick question-answer made from the peers. It was recommended that each member presentation be limited to ten minutes and the preliminary questions limited to another ten minutes. Concluded the presentations, a round table, multidisciplinary discussion were conducted, to perform trades between all sub teams to achieve viable solutions that fulfil the teams needs and allows mission success. The last step was the execution of the

MDR, by evaluating and validating the documentation produced by the active members of the project;

5º One of the main focus during the meeting was about the selected probes to measure the plasma around the satellite during its mission, since the initially defined Langmuir probes[1] were not completely accepted by the audience. From every suggests made, the agreement was achieved when the multi-Langmuir probes were considered, being so the choice adopted for the project. Another important focus was the coordination between the scientific researchers and the engineering team to ensure that everyone was working towards the same objectives and the methods applied were compatible between them. Finally, the members gather all documentation necessary to perform the MDR and execute it, which allowed a revision of the work done and highlighted some minor discrepancies. Due to the small discrepancies, the team agreed in continue with the planning but corrective actions were considered to eliminate them;

6º Despite the constructive and productive results achieved, it was expected that the results were more positives, due to the lack of various subjects discussed. One of the considered gaps in the project which could explain the missed objectives of the meeting is related to very few people are working at MECSE, and some of them are still getting the first steps on it. Even though, the MDR objectives were considered satisfactorily achieved and the team agreed that MECSE could enter the next lifecycle phase.

4.2.3 Management planning

The management planning of MECSE started after the beginning of the project, and due to that the first step consisted on understanding the work already performed and the management methodologies adopted (empirically) by the members already working. The methodologies were not documented and so it became urgent to inquire the members about what they assumed as correct actions to achieve the objectives successfully.

Despite the singularity of an educational project, the methodology should be aligned to the methodology defined and implemented by CEiiA on their own projects, at least the most similar possible.

[1] Langmuir probe is a device used to determine the electron temperature, electron density, and electric potential of a plasma.

4.2.3.1. Project charter

The first step was to develop a project charter, which highlights the entire project during the conceptual phase. During this phase, the specific documentation is very little and the conceptual studies are still on an embryonic stage, and so the cornerstone of the project is its charter.

The MECSE project charter focuses on several subjects, which will be described below on this dissertation, emphasising on the following:

- Project charter purpose – this topic acts as an introduction for the project charter. It highlights the main focus of the document, and the reasons for generating itself;
- Executive summary – provides information related to development. The executive summary is composed by the objectives of the project, the assumptions and constraints, the main risks identified at an early stage of the project, the preliminary costs estimation, and the predicted schedule for execution of the project;
- UBI's/ CEiiA's benefits – this topic is reserved for the benefits that the project will generate for the stakeholders. Nowadays, MECSE project has two stakeholders, UBI and CEiiA, and the outcomes for them are described on this section;
- Project framework – on this chapter of the charter it is possible to acquire more information about the background of the project. It describes the motivation for the project, the reasons for the partnership between UBI and CEiiA for the implementation, and briefly the team constitution;
- Scope – the scope describes the various fields of work, which are the engineering field and the scientific field;
- Objective – MECSE has some objectives, distributed for three major areas, the educational objectives, the scientific objectives, and the technological objectives. In this chapter are referred those objectives for each area;
- Assumptions and constraints – like any other project, MECSE project has assumptions and constraints that should be respected for a successful implementation. This section lists these assumptions and constraints and presents a brief description of each one;
- Project plan, deliverables and milestones – analysing this section of the charter, it is possible to have a better understanding about the schedule and about the main phases of the project;
- Project risks – the project risks section lists the possible risks found at the preliminary trade-offs. Each risk of the list is identified by an unique ID, it is related to a specific project phase, has a brief description of the risk and the consequences for the project, allowing a better understanding, and the risk mitigation measures are identified;
- Resources – every project should perform a preliminary resources assessment to evaluate the feasibility of the project. In this section is presented the preliminary resources

consumption for the entire MECSE project implementation, following the guidelines provided by CEiiA;

- Management – the management chapter provides a brief description about the project team organisation and about the stakeholders and their responsibilities for the completion of the project;
- Project structure – this section highlights the formal structure of MECSE project, such as the product breakdown structure and the work breakdown structure, and provides information about communication, data storage, and configuration management;
- Annexes – the annexes of the document support the information presented on the charter providing it more detailed. Due to the current project phase, the information on the annexes may be updated. The annexes are:
    - Annex A - Project plan: this annex display the project plan, produced by a computational tool, the ProjectLibre© software;
    - Annex B – Risks management plan: this plan provides deeper information related to the project risks. Each risk is delegated to a mitigation responsible and have a due date for the mitigation;
    - Annex C – Resources allocation: the resources allocation provides the preliminary resources estimations for the entire MECSE project, emphasising the resource needs and the production costs;
    - Annex D – Communication plan: in this annex is described every types of communication for MECSE and the communication guidelines recommended for a communication standardisation;
    - Annex E – Configuration management: this annex provides a description of which software is being used on MECSE project and its purposes. The configuration management is an important tool for MECSE since it ensures the proper transition from one leaving member to his successor.

Due to the extension of this charter and some of the information contained on it will be displayed further, the author opted for not attach it in this section, being possible to consult on Annex A of this dissertation.

At this phase of the project, the specific information has many gaps and it is hard to elaborate an accurate plan for all project phases. However, it is mandatory having any type of guidance. The project charter assumes extreme importance for the project since it is the main guideline for the early phases.

For MECSE project, the project charter is adapted from CEiiA's management, ensuring the coherence between MECSE guidelines and CEiiA's guidelines, considered crucial due to the partnership established for the implementation of the project.

The project charter proposed for MECSE project, as well as the following work produced, follows the approval chain applied by CEiiA. This means that a member produces the document, another member performs a revision of the document, and then a CEiiA's engineer approves the document. For MECSE project Tiago Rebelo is the CEiiA's engineer responsible for approving all the documentation and decisions made.

4.2.3.2. Decision approval chain

During the process of implementation of a formal PM methodologies the formal decision process approval was created, since at the time the decision flow was completely absent. This decision has revealed extremely important, considering the reduction of time between the necessity for a decision and the decision making. An example of the scheme is represented on Figure 4.3, presented below:

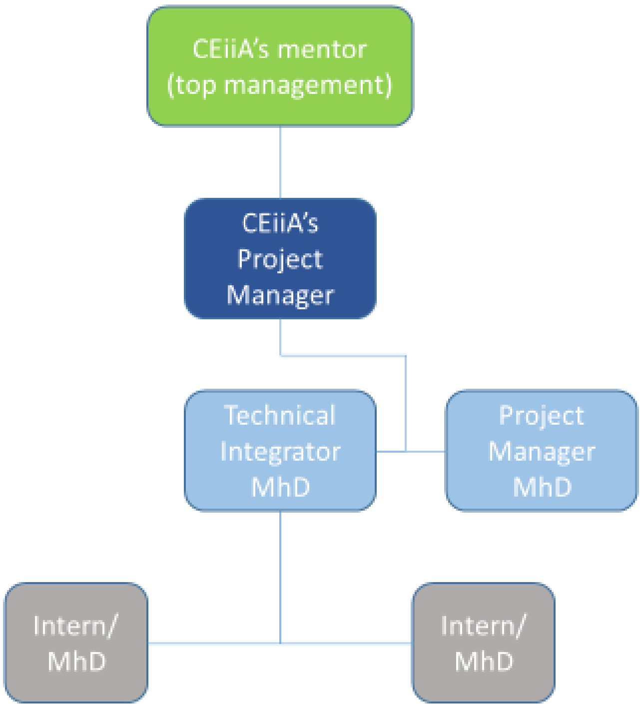


Figure 4.3 PM decision approval chain.

This specific scheme is the approach used to make a decision related to management of the project, and concerns four hierarchic levels, identified by blocks of different colours. Due to the nature of MECSE, the flow adopted is generic, facilitating the substitution of the students leaving the project once they finish their academic degrees, or for another reason. It is important to refer that the number of students allocated on the flows (interns or M. Sc.) are for reference only, and could be different from chart, depending on the work load on each subsystem and the resource availability.

Some subsystems display a different flow of decision approval, which are attached to this dissertation on Annex B. Displayed on the same annex the user can find the system approval chain, which is the combination of all subsystems decision approval chains referred before, adding the top levels of management usually implemented by industry to complex projects.

4.2.3.3. Decision process flow

Connected to the decision approval chain, a decision process flow has been developed (Figure 4.4), highlighting the most important inputs and clarifying the steps recommended for a better decision as possible at the time.

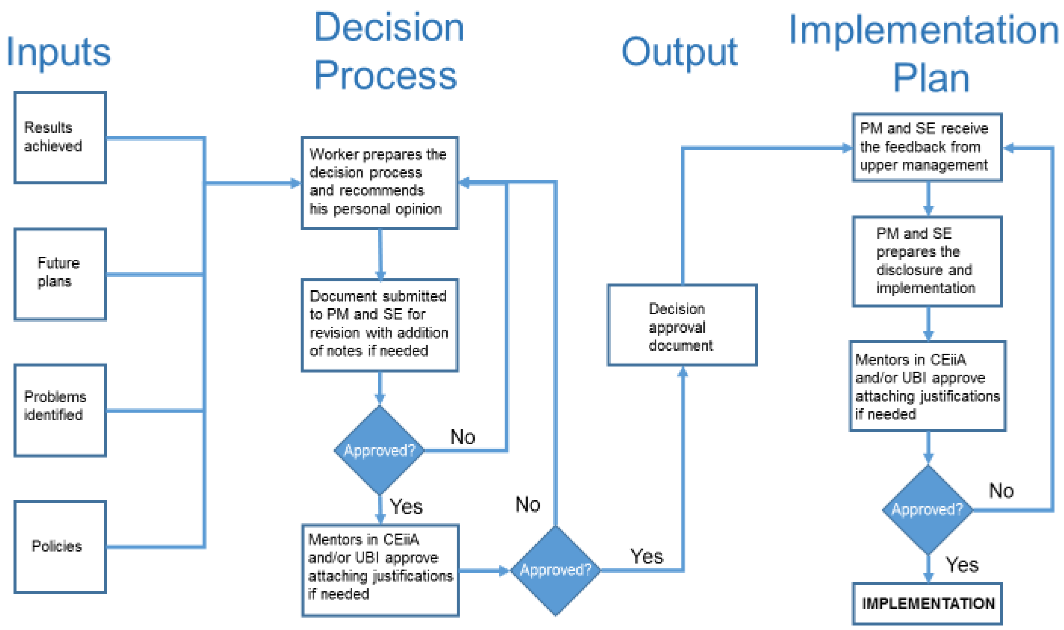


Figure 4.4 Decision process flow.

Combined decision approval chain and process flow resulted in better decisions made for the challenges faced during this lifecycle phase of MECSE, at the same time that the required time were considerably reduced, impacting positively the project schedule.

4.2.3.4. Costs estimation

MECSE project follows the guidelines adopted for CEiiA. At the preliminary phase, the costs estimation does not provide detailed information, instead it provides a target value for the entire project execution.

The estimation displayed on Figure 4.5 is supported by Annex C of MECSE project charter. This estimation was performed at the project initiation, to evaluate the number of resources necessary to carry the entire project.

Type	Cost (€)
Resources	81657,6
Production	66403,08
Launch *	0

Overall (€)
148060,68
Overall with 25% overhead (€)
185075,85

* The launch costs are assumed as zero at this point due to the objective of apply to ESA program which supports the costs of launch

Figure 4.5 Costs preliminary estimation.

Some considerations were made to meet the costs mentioned at Figure 4.5, namely the cost per hour of work of all members on the project and the expenses with the logistics. The specific information related to this expenses are not shown in this section, however is available in annex A.

The considerations were based on the costs of production applied by CEiiA, not on commercialisation costs.

(*) The expenses of launch for now are considered null due to the intention of having the MECSE associated to an ESA program which may support these costs.

4.2.3.5. Work Packages

For a better understanding of the necessary steps to meet the objectives of the project within the defined schedule, the whole work since the kick-off until the launch of the satellite were divided into work packages.

The logic used on MECSE is represented on Figure 4.6, which divides the work firstly for segments, then for main tasks, and inside the most complex main tasks are even divided into small tasks. The objective is decomposing a complex work into small manageable tasks or activities, which could be assigned to a member of the team or a sub-team.

Figure 4.7 represents the lower level work packages division adopted by the project, specifically for the subsystems that will be developed for the satellite. This lower level was only assumed for segment “3. Development” being the most complex segment and with the highest human resources allocation will be needed for meeting the deadlines.

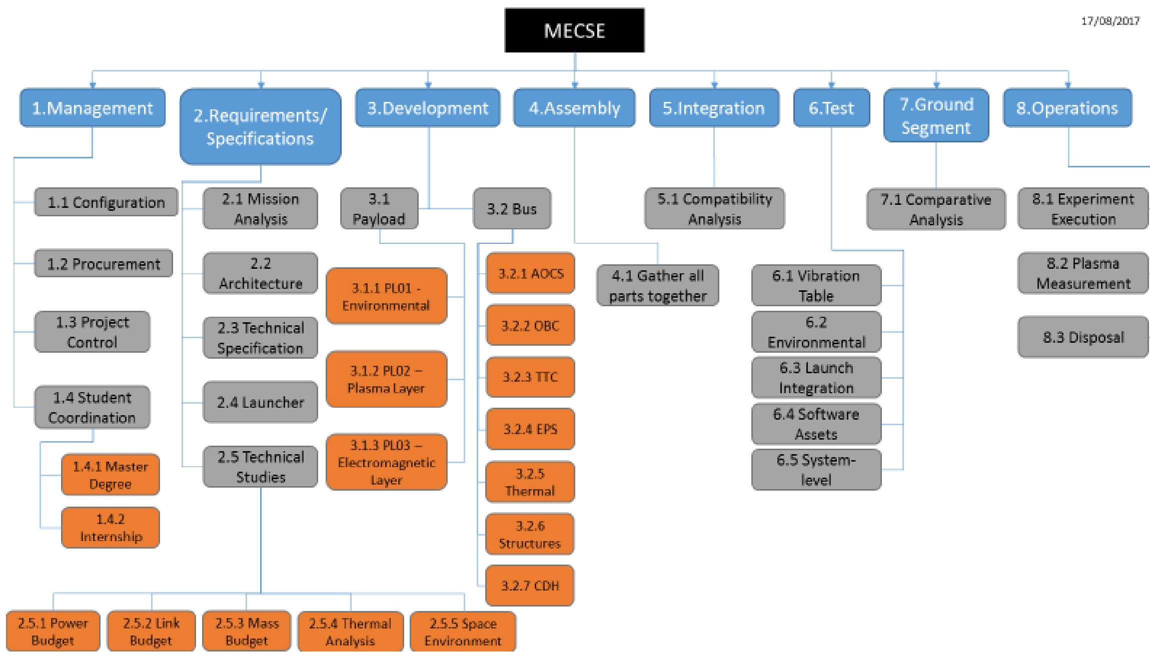


Figure 4.6 MECSE Work Packages (WP).

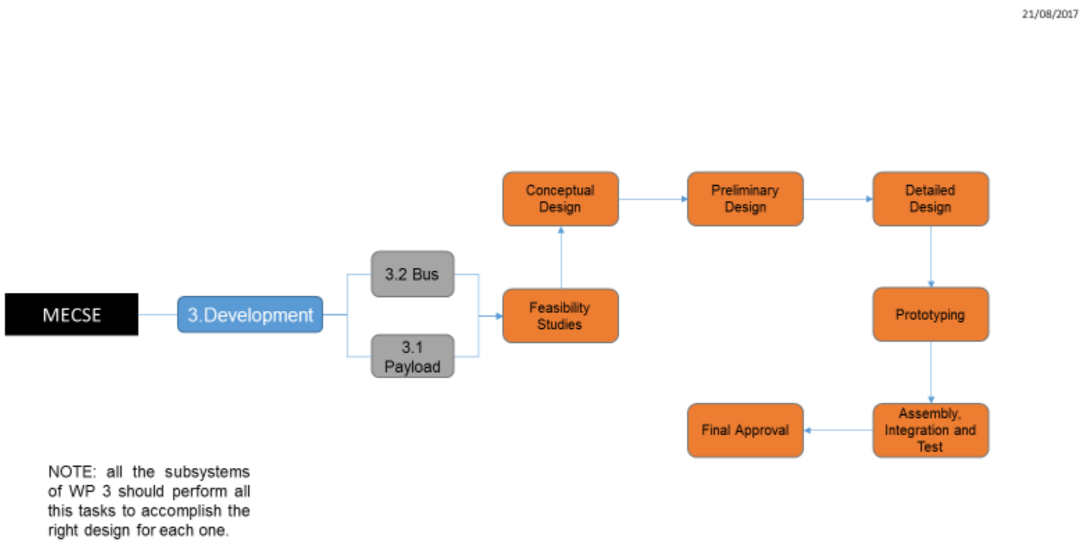


Figure 4.7 MECSE development segment subsystem tasks.

4.2.3.6. Work Breakdown Structure

The WBS of MECSE system is divided on first level by its phases, for a better comprehension of the tasks by phase necessary to successful project.

Due to the immediate needs of planning being focused on phases 0/A and B, the WBS designed only gather lower level of information for those. The MECSE WBS is represented by Figure 4.8 and Figure 4.9.

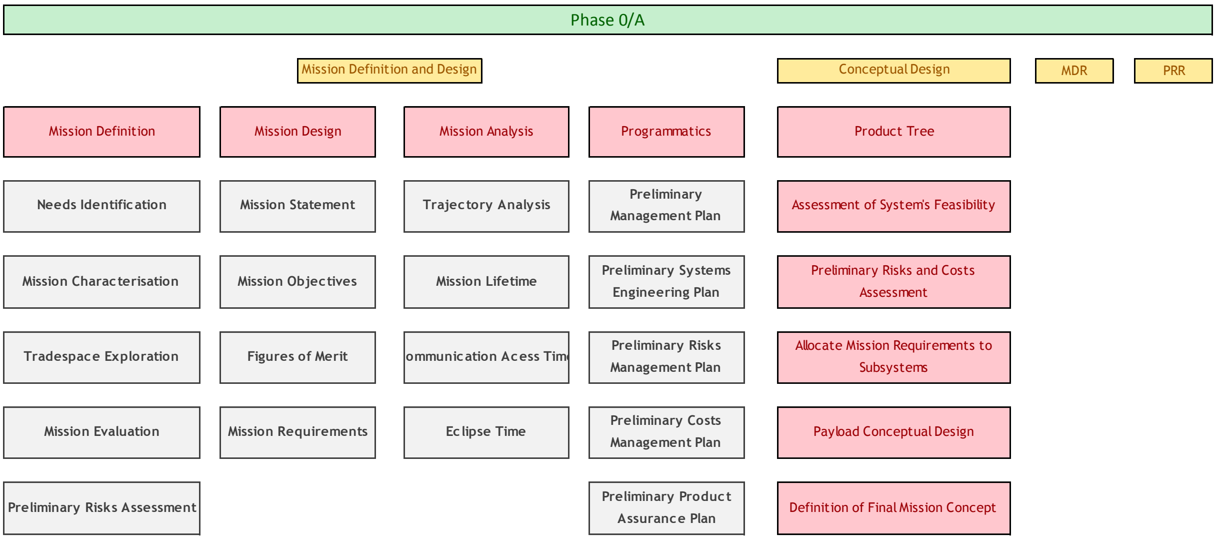


Figure 4.8 MECSE system work breakdown structure (part 1).

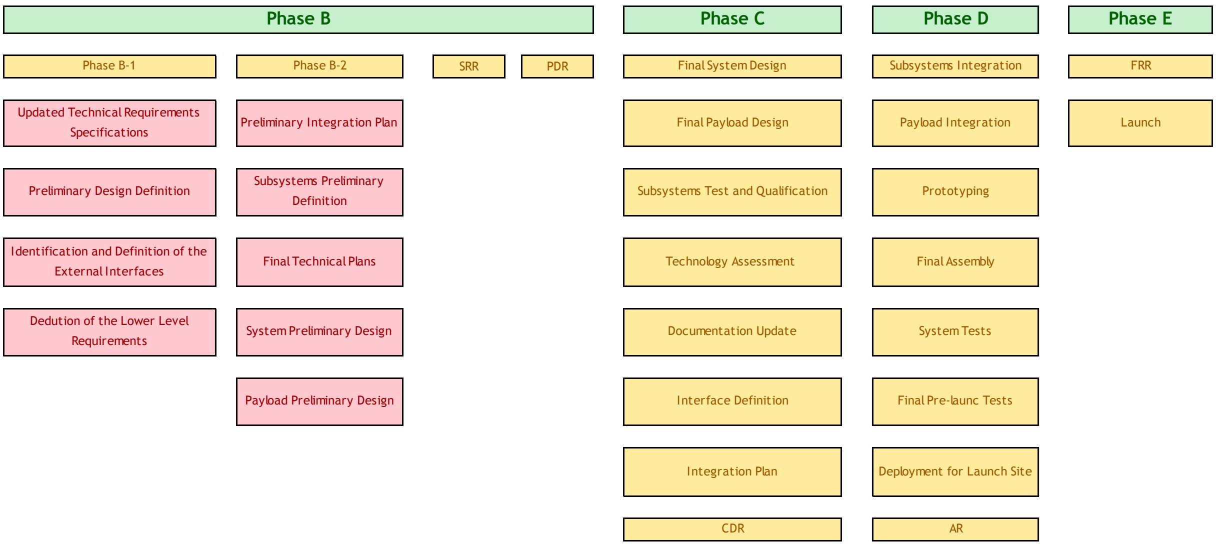


Figure 4.9 MECSE system work breakdown structure (part 2).

The different colours shown in Figure 4.8 and Figure 4.9 intend to make a clear distinction between each WBS level. The green label represents the project phases (WBS level one), the yellow label represents the sub-phases (WBS level two), the red label represents the major activities (WBS level three), and the grey label represents the tasks (WBS level four).

Breaking down the system WBS into more specific tasks could consume large amounts of time, and that can be “translated” for money. At the end of a project, this could be the difference between a project that respects the costs constraints and a project that do not. For this reason, is recommended to not decompose the system in more than four levels.

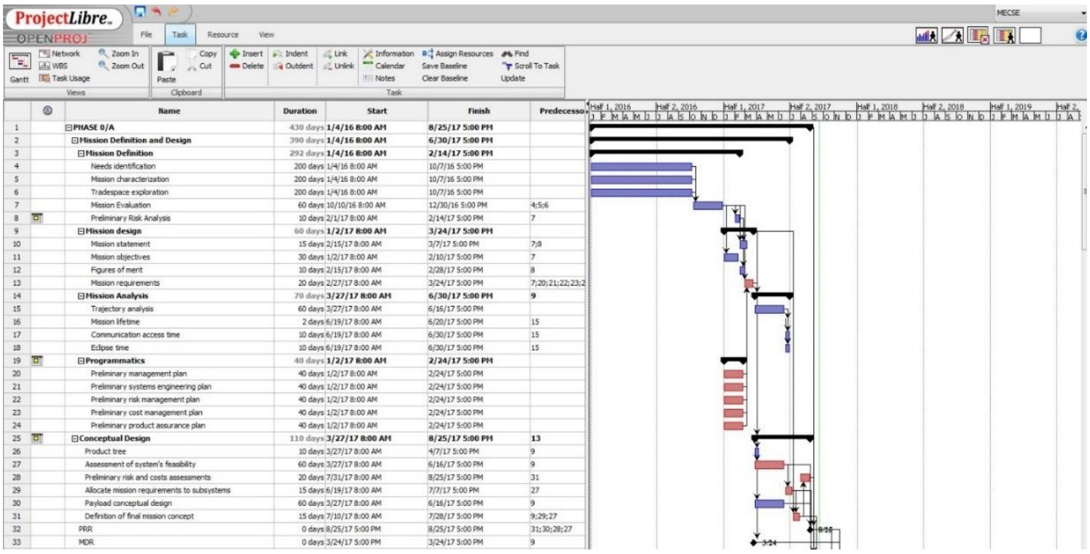
4.2.4 Schedule management

The schedule management of MECSE is supported by a computational tool named “ProjectLibre©” which is an open source project management tool. This tool allows the user to insert the activities of a project, indent or outdent them consonant with the level of the WBS. With ProjectLibre© the management of the schedule becomes more accurate and flexible.

The activities can be grouped and their dates can be modelled according to the time constraints applied to the project.

This tool also provides an easy way to assess the project’s performance, comparing the actual work against the predicted work. Thus, if some delays arise, the tool highlights them, alerting for corrective actions. These delays could jeopardise the project schedule and possibly the project itself.

The MECSE preliminary schedule is shown on the following figures:



	Name	Duration	Start	Finish	Predecesso
1	PHASE 0/A	430 days	1/4/16 8:00 AM	8/25/17 5:00 PM	
2	Mission Definition and Design	390 days	1/4/16 8:00 AM	6/30/17 5:00 PM	
3	Mission Definition	292 days	1/4/16 8:00 AM	2/14/17 5:00 PM	
4	Needs identification	200 days	1/4/16 8:00 AM	10/7/16 5:00 PM	
5	Mission characterization	200 days	1/4/16 8:00 AM	10/7/16 5:00 PM	
6	Tradespace exploration	200 days	1/4/16 8:00 AM	10/7/16 5:00 PM	
7	Mission Evaluation	60 days	10/10/16 8:00 AM	12/30/16 5:00 PM	4;5;6
8	Preliminary Risk Analysis	10 days	2/1/17 8:00 AM	2/14/17 5:00 PM	7
9	Mission design	60 days	1/2/17 8:00 AM	3/24/17 5:00 PM	
10	Mission statement	15 days	2/15/17 8:00 AM	3/7/17 5:00 PM	7;8
11	Mission objectives	30 days	1/2/17 8:00 AM	2/10/17 5:00 PM	7
12	Figures of merit	10 days	2/15/17 8:00 AM	2/28/17 5:00 PM	8
13	Mission requirements	20 days	2/27/17 8:00 AM	3/24/17 5:00 PM	7;20;21;22;23;2
14	Mission Analysis	70 days	3/27/17 8:00 AM	6/30/17 5:00 PM	9
15	Trajectory analysis	60 days	3/27/17 8:00 AM	6/16/17 5:00 PM	
16	Mission lifetime	2 days	6/19/17 8:00 AM	6/20/17 5:00 PM	15
17	Communication access time	10 days	6/19/17 8:00 AM	6/30/17 5:00 PM	15
18	Eclipse time	10 days	6/19/17 8:00 AM	6/30/17 5:00 PM	15
19	Programmatics	40 days	1/2/17 8:00 AM	2/24/17 5:00 PM	
20	Preliminary management plan	40 days	1/2/17 8:00 AM	2/24/17 5:00 PM	
21	Preliminary systems engineering plan	40 days	1/2/17 8:00 AM	2/24/17 5:00 PM	
22	Preliminary risk management plan	40 days	1/2/17 8:00 AM	2/24/17 5:00 PM	
23	Preliminary cost management plan	40 days	1/2/17 8:00 AM	2/24/17 5:00 PM	
24	Preliminary product assurance plan	40 days	1/2/17 8:00 AM	2/24/17 5:00 PM	
25	Conceptual Design	110 days	3/27/17 8:00 AM	8/25/17 5:00 PM	13
26	Product tree	10 days	3/27/17 8:00 AM	4/7/17 5:00 PM	9
27	Assessment of system's feasibility	60 days	3/27/17 8:00 AM	6/16/17 5:00 PM	9
28	Preliminary risk and costs assessments	20 days	7/31/17 8:00 AM	8/25/17 5:00 PM	31
29	Allocate mission requirements to subsystems	15 days	6/19/17 8:00 AM	7/7/17 5:00 PM	27
30	Payload conceptual design	60 days	3/27/17 8:00 AM	6/16/17 5:00 PM	9
31	Definition of final mission concept	15 days	7/10/17 8:00 AM	7/28/17 5:00 PM	9;29;27
32	PRR	0 days	8/25/17 5:00 PM	8/25/17 5:00 PM	31;30;28;27
33	MDR	0 days	3/24/17 5:00 PM	3/24/17 5:00 PM	9

Figure 4.10 MECSE chart (part 1).

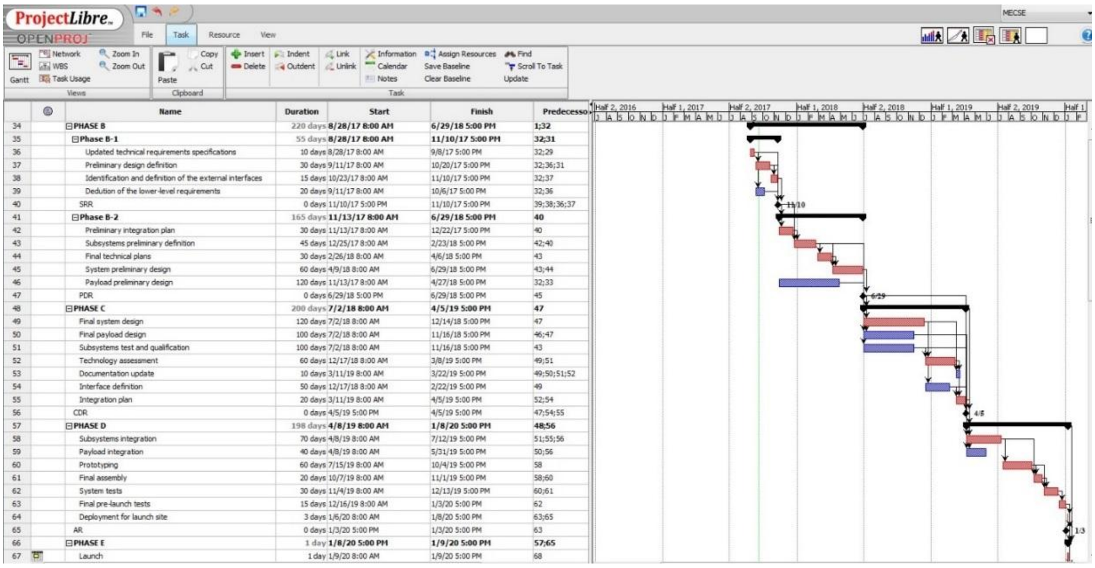


Figure 4.11 MECSE chart (part 2).

This chart already contains the most important activities of MECSE. However, due to the current project phase, the chart may be updated. These updates are needed when some of the WP still need a further study to assess the work load.

The studies undertaken can highlight some activities needed which are not scheduled, or the necessity of dividing some of the activities into smaller tasks. If the last case occurs, the group of tasks should be at lower WBS level of decomposition to the respective activity, ensuring coherence on the schedule chart.

The schedule presented assumes the project conclusion in the “launch” activity. However, that does not necessary means the launch day will be as scheduled, due to the launch opportunity depend on the frequency of ESA uses their rocket “VEGA”.

The difficulty in predicting an accurate date is related to the fact that 2020 rocket launch is not scheduled yet. Thus, the goal is getting the satellite ready for launch at the date estimated date.

The critical path, marked by red bars, have serious implications on the project schedule. These activities should not suffer any delays, otherwise those will be disseminated through the subsequent activities.

Supported by the project schedule, becomes possible to define the project main deliverables. The MECSE main deliverables are listed on Table 4.1, assigned to a responsible entity of the project and with a defined due date.

Table 4.1 MECSE project main deliverables.

Responsible	Deliverable	Due date
CEiiA	CubeSat requirements report	30/06/2017
CEiiA	Equipment (payload and subsystems) report	14/12/2018
CEiiA	Mechanical development report	14/12/2018
UBI	Theoretical definition for scientific payload report	17/08/2018
CEiiA	Payload assembly	19/07/2019
CEiiA	Subsystems assembly	04/10/2019
CEiiA	Final assembly and delivery	01/11/2019
CEiiA	Final tests analysis, post-launch	01/02/2020

Performing an analysis on the WBS of MECSE, the main milestones could be organised as shown on Table 4.2.

Table 4.2 MECSE project main milestones.

WBS	Task name	Due date
1.1.1	Mission definition	14/02/2017
1.1.2	Mission design	24/03/2017
1.1.3	Mission analysis	30/06/2017
1.1.4	Programmatics	24/02/2017
1.2	Conceptual design	25/08/2017
2.2.4	System preliminary design	29/06/2018
2.2.5	Payload Preliminary design	27/04/2018
3.1	Final system design	14/12/2018
3.2	Final payload design	16/11/2018
4.1	Subsystems prototyping	04/10/2019
4.2	Payload prototyping	19/07/2019
4.3	Final assembly	01/11/2019
4.4	System tests	13/12/2019
4.6	Final test	03/01/2020
5.1	Launch	09/01/2020

These main milestones are all the activities of MECSE which must be performed to achieve the project's goals. Despite possible reviews on the project schedule, these milestones could only suffer changes on the estimated date or the WBS unique number.

The Table 4.2 provides an overlook on the project, since its early beginning until its closure. By the analysis of this table and comparing with the real project work, becomes possible to estimate any possible delays.

4.2.5 Risks management

Risks are inherent to every project. Dealing with them could be a real time consuming process, although it is crucial. The risks management allows the project manager to assess the risks associated to the project and prepare the appropriate mitigation plans. The mitigation plan is assigned to a team member, who will be responsible for implementing the mitigation measures.

Risks Log							
Activities/ Phase	Open date	Description	# ID	Impact on project	Close date	Mitigation measures	Mitigation Responsible
The origin of the risk	*Risk was found on:*	*Description of the risk*	*No. of risk*	*Changes/ impact on work*	*Risk was solved on:*	How to reduce and/or eliminate the risk	Person Responsible for eliminate/mitigate the risk
Phase B	20-07-2017	If the correct margins are not applied, mass budget may not be respected	1	Recalculation of the mass for all parts of the subsystems	11-08-2017	Apply at least 20% margin on preliminary definition and 5-10% on detailed definition. Due date: 16-08-2017	The responsible for each subsystem should ensure the application of mitigation measures recommended
Phase B	18-07-2017	Dificulty on predict the magnetic field on the specific distance of the center of the coil	2	Possible erros on the predicted values for the magnetic field		Validate the software values, need a formula to do it. Due date: 06-04-2018	Payload subsystem responsible
Phase B	10-08-2017	The PLME will necessitate a specific peak power to be performed	3	If the peak power will not satisfy the needs of the experiment, the scientific requirements will not be fulfilled		Ensure that the EPS will guarantee the peak power needed to run the experiment, apply a safety margin. Due date: 06-04-2018	The EPS subsystem responsible
Phase E	11-08-2017	The measurements of plasma should be as accurate as possible, so the environmental conditions should be more close to plasma layer at re-entry as possible	4	If this relation will not be considered, the values acquired by performing the experiment could be unrealistic		Perform the calculations and the characterization of the mission having this constraint well present. Due date: 05-04-2019	The Mission Analysis and Payload subsystems responsibles
Phase A	14-08-2017	The mass budget should be conform with the CubeSat standards and with the ECSS standards	5	If the mass budget will not be respected, the project could be rejected or the launch costs could be highly increased	11-07-2017	Ensure the right application of the standards on the preliminary phases and the right margins on each project phase. Due date: 25-08-2017	The responsible for each subsystem should ensure the application of mitigation measures recommended
Phase E	14-08-2017	The satellite should be able to communicate with the ground on a regular basis to deliver the scientific data	6	If the satellite could not communicate with the ground station, the scientific data collected could not be accessed and evaluated		Guarantee an alternative communication channel that could ensure the data transfer if the main communication system fail. Due date: 27-04-2018	The Communication and Data Handling subsystem responsible
Phase B and C	17-08-2017	Due to the in-house built of the satellite structure (unique concept), the likelihood of fail is bigger	7	If the satellite is launched with some structural fail, the probability of loss is greater		As soon as possible, in the detailed design phase, allow the prototyping and test for the entire structure to ensure is viability. Due date: 14-12-2018	Mechanic System and Structures responsible
Phase E	06-09-2017	The satellite should be able to communicate with the ground to understand its conditions and ensure the right orbit and other parameters	8	If the satellite could not communicate with the ground station, becomes an uncertainty if it still on its track		Guarantee an alternative communication channel that could ensure the tracking and control of the satellite. Due date: 14-12-2018	The Communication and Data Handling subsystem responsible
All phases	07-09-2017	Loss of knowledge, due to the replacement of a team member	9	If any of the volunteer participants of the project leave it and does not give any feedback about the work made or how to manage the tools adopted, the knowledge could be loss	15-09-2017	All the members that will leave the project soon should elaborate a report where they explain what they have done, how they did it and the future steps	Head of Unit
Phase B, C and D	13-09-2017	Mission cost too overwhelming to continue	10	If costs constraints were not respected, the project could be terminated due to its higher than maximum predicted costs		Guarantee a periodic review to the costs (past and future) to ensure that the project fits on its financing. Due date: 03-08-2019	Project Manager
Phase C	13-09-2017	Software interfacing with PLME delayed	11	If the software were not delivered in time, the project could suffer delays and loose the window of launch		Ensure that the teamworker assigned for the task will deliver the proper software in time. Due date: 29-06-2019	Payload subsystem responsible
Phase B and C	13-09-2017	PLME team does not provide documentation needed for MECSE design to continue in timely manner	12	A complete rethinking for the design could arise, provoking schedule delays and costs increase		Ensure a proper development of the PLME and its corresponding documentation. Due date: 23-02-2018	Technical Integrator

Figure 4.12 MECSE risks management plan.

MECSE risks management plan should be more rigid for most severe risks, and continuously monitored.

The MECSE risks management plan (shown on Figure 4.12) gathers their associated risks and identifies where the risk can occur, which impact may have on project, the mitigation measures and the responsible person for implementing those measures.

Due to lack of expertise on spacecraft's design, specifically CubeSat's design, some of the risks referred on risks management plan occurred prior to establishment of mitigation plan. Those risks entailed rework of some activities.

For a successful implementation, the information should be spread by the team members, ensuring that everyone is aware of critical choices.

The risks management plan should be periodically updated, whenever a risk rises the impact on future work shall be evaluated.

Another consideration while assessing the risks of a project are their likelihood and consequences. L-C matrix is widely used and is probably the better way for understanding which risks should be immediate mitigated and which could be mitigated slowly.

Figure 4.13 represents the L-C matrix adopted for risks analysis on MECSE system. The green blocks are the least severe L-C values for project and the red blocks are the most severe. This scale needs a rank from one to five for likelihood and for consequence.

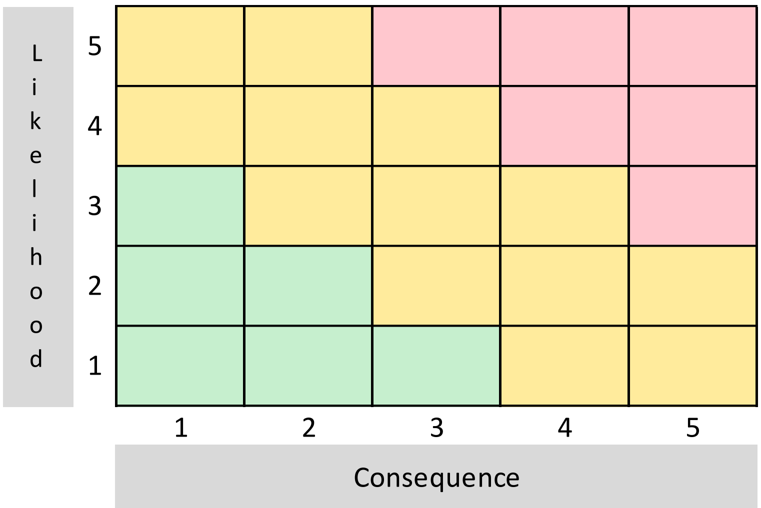


Figure 4.13 L-C matrix adopted by MECSE system.

To fill the L-C matrix, a description of ranks is essential. MECSE adopted the Department of Defence (DoD) rank, which is presented on Figure 4.14.

Score	Definition
High	An event that is extremely or very likely to occur and whose occurrence will impact the project's cost (and/or schedule) so severely that the project will be terminated or will cause significant cost (and/or schedule) increases (e.g., increases of more than 5 percent) on the project; this risk should be escalated (where possible) and reviewed frequently.
Medium	An event that has a 50-50 chance of occurring and, if it occurs, will cause noticeable cost (and/or schedule) increases (e.g., increases of not more than 5 percent) on the project; this risk should be reviewed regularly.
Low	An event that is unlikely or very unlikely to occur and, if it occurs, will cause small or no cost (and/or schedule) increase that, in most cases, can be absorbed by the project.

Figure 4.14 DoD risks rank for L-C matrix.

Applying the L-C matrix of Figure 4.13 to the risks identified on Figure 4.12 generates the Table 4.3. This table shows the priority of the risks and the colours intend to highlight the risk position on the L-C matrix.

Table 4.3 MECSE mission risks with identification of priorities.

Risk ID	Likelihood	Consequence	L-C value	Priority
1	1	3	3	10
2	2	2	4	9
3	4	4	16	1
4	2	1	2	12
5	1	3	3	11
6	2	4	8	3
7	2	4	8	4
8	1	4	4	7
9	3	2	6	5
10	2	5	10	2
11	3	2	6	6
12	1	4	4	8

Due to the specificity of the project, and to a considerable lack of knowledge in some disciplines of CubeSat development, the project displays many important risks (yellow label). However, a good indicator is the fact that only one of the identified risks have the red label, which means that should be carefully monitored and a corrective plan should be created.

4.2.6 Documentation and data management

Documentation and data management can be a challenging task for project manager. Their proper storage plays a key role, acting as a project library. Thus, a chaotic project has a higher failure probability.

Due to each project characteristics, the management should be adapted to fulfil the needs for organisation. On the MECSE case, the convention used is directly related to the subsystems and the sub-teams.

Table 4.4 Documentation generation naming convention.

Subsystem	Abbreviation	Reference Numbers Beginning
Management	MAN	0000
Mission Analysis	MR	0100
Payload	PL	0200
Electrical Power System	EPS	0300
Mechanic System and Structures	MSS	0400
Thermal and Magnetic Isolation	TCS	0500
Attitude and Orbit Control System	AOCS	0600
Communications and Data Handling	COMM	0700
Configuration	CONF	0800
Systems Engineering	SYS	0900
Miscellaneous	MISC	1000

The documentation standardisation is extremely important to the project. If all members working on project follow the same guidelines, the product of their work will be coherent when getting all together.

The file naming convention document provides for all the participants on MECSE the guidelines which should be strictly respected when generating documentation or data.

The MECSE documentation folder is organised as described in Table 4.4, and keeping this up-to-date is a project manager responsibility. All members are responsible for ensuring the correct documentation production according to the guidelines.

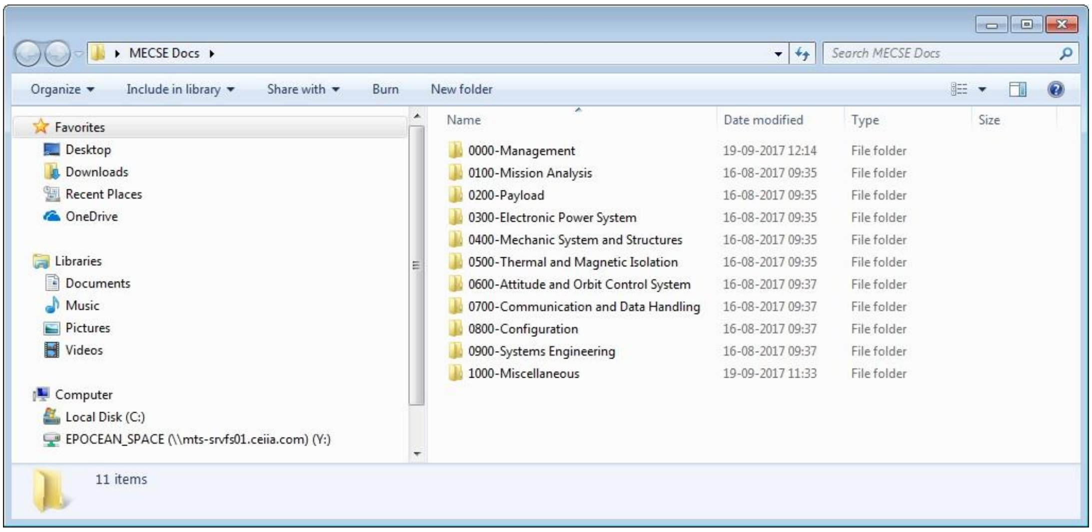


Figure 4.15 MECSE documentation folder organisation.

The numerical code displayed at each folder is considered a unique ID, relating automatically a document to its specific subsystem. The numerical code logic is very simple to understand, the first two number identifies the subsystem, the last two number represents the numeration of the document. Thus, after the four digit code, separated by a " – " comes the document version.

By watching the Figure 4.16, becomes easier to understand the different parts of the numerical code.

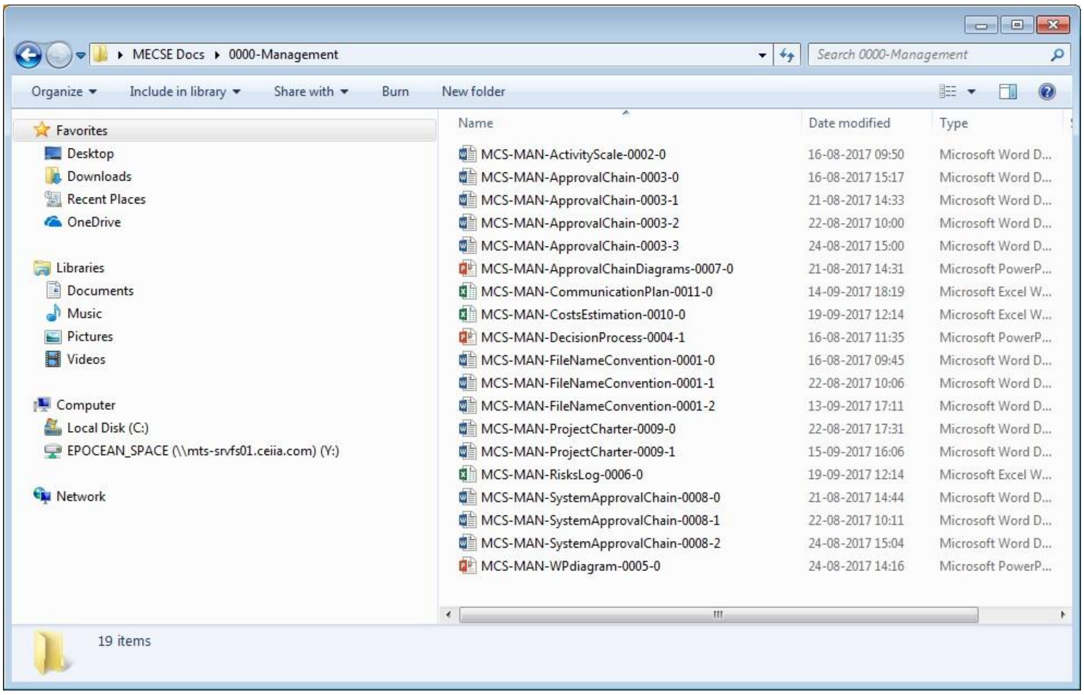


Figure 4.16 Management folder organisation.

It is important to refer that each subsystem document has its own numeration (for example the first document of "Payload" will be numbered as 0201).

The last step performed during the implementation of PM methodologies for documentation and data management was the preparation of templates. The templates produced were:

- Presentation template;
- Word template;
- Work package breakdown description list template.

The correct application of the templates referred above constitutes an increment on organisation, emphasising project documentation standardisation.

4.3 Subsystems status

The MECSE project, as any other satellite, needs various support subsystems. These subsystems have many different functions and some of them are available of-the-shelf. However, the mission specifications may require new technology concepts, and so the team has chosen to try to design and manufacture all the subsystems in-house. Due to this decision made at conceptual phase, is important to track the progress on each subsystem, and include it on the project plan.

The subsystems status shown on Table 4.5 was obtained at mid-September of 2017.

For planning purposes, the "Further work" column displayed on the Table 4.5 is organised by relevance. The first step is considered the most important to perform first. However, some work could be performed in parallel.

Despite not being referred on "Work performed" column, all the subsystems already have their specific requirements and design drivers defined. Decision was made to not include it on Table 4.5 due to being common to all.

Table 4.5 MECSE current subsystems status.

MECSE subsystems status point		
Subsystem	Work performed	Further work
EPS	Excel containing power budget; preliminary batteries and solar panels sizing.	Tradestudies for a accurate evaluation of the proper power management and power storage.
AOCS	Conceptual analysis on sensors; preliminary studies on control methodologies.	Tradestudies on sensors and on control components.
TTC	Conceptual frequency band selection.	Preliminary assessment of the selected frequency band; tradestudies on antennas and componentes needed for subsystem; selection of the components.
CDH	Conceptual analysis.	Assess the software needs; conceptual components tradestudies; creation of a data flow chart.
MSS	Conceptual design and preliminary design; thermal, strutural, and linear static analysis.	Tradestudies on mechanisms to support AOCS; tradestudies on deployment mechanisms.
TCS	Not started yet.	Analysis on radiation isolation, and another isolation materials; tradestudies on magnetic isolation.
PL	Tradestudies for materials and concept; payload mass optimisation; payload power consumption optimisation	Experimental validation of the PLME; preliminary payload design (3D CAD); tradestudies considering the phisics of MECSE;

Chapter 5 – Conclusion and future work

5.1 Results

At the beginning of this study and implementation, the MECSE project did not follow any formal management methodology, being implicit on each team member work and driven by personal judgement. Despite many similar projects opted for this approach, a formal project management methodology is an important support for achieving the objectives successfully, optimising costs, and resources needed.

Due to the lifecycle of MECSE being about four years and this implementation only covers a few months of the entire project, some steps could not be made. The project management should start before the actual project work starts and finish with the project completion. However, the results achieved during the implementation of management process could be considered as a good indicator that project management is a valuable tool.

Nowadays, the project follows the methodologies applied and the guidelines defined, and the reflection of that is the improvement on management and communication, contributing to a positive work environment. This environment motivates the team, and a motivated team is a team which work harder and produces better results.

The difficulties found while implementing the project management methodologies were essentially the fact that the project was already running at the beginning of the implementation and the lack of knowledge on management methodologies. However, the industry is investing a lot in this discipline and is possible to acquire information and complement the knowledge supported by some research. The main “guides” on this dissertation were, mainly, ESA and NASA, since they are the two most important space agencies in whole world, and their credits are unquestionable, providing the tools to get the job done successfully.

Since this is an educational project, the main goal is not getting profit. Instead, it is providing concrete knowledge to students on space matters, not only theoretical. Due to this, is recommended that more students could be invited to join the team and work in a real space project.

5.2 Conclusions

This dissertation was produced within the framework of implementing a formal Project Management methodologies into an educational project performed in cooperation with the industry. Since the MECSE project did not have adopted any formal methodology at the beginning of the dissertation, the proposed objectives were, mainly, defining a schedule for the entire project execution, establishing guidelines for team building to have a clear vision about the team gaps, elaborating documentation essential for the management of the project such as the approval flows and the project charter, and assessing and documenting the risks associated to the project.

Since CEiiA does not have any background in CubeSats production, the MECSE project acts as a benchmark. However, the lack of knowledge forced the team and CEiiA's mentors to consult external experts to ensure the correct project elaboration and implementation. This has caused some delays and small errors.

During the elaboration of this dissertation the methodology adopted for project management was according to the ESA and NASA guidelines, for space projects. These methodologies guided the team for meeting the international standards, and forced some changes on the initial scope, mainly on the project timeline, which initially was defined since 04th January 2016 until 03rd June 2019. However, the assessments performed have demonstrated that the initial timeline was too short and needed to be refined, which happened supported by the schedule elaborated.

Due to the partnership established between UBI and CEiiA, the methodology selected for MECSE project was intended to be in conformance with the CEiiA's internal guidelines and methodologies for projects, more specifically those used in Aerospace and Ocean Area. The documentation described into "Chapter 4 – Project Management Implementation" was the contribution of the author of this dissertation for MECSE project. As any other project, MECSE documentation was produced, revised and after approved. Each one of these tasks was made for different members, the first two for UBI students and the last (approval) for the engineer responsible for the CEiiA's Aerospace and Ocean Area, who is Tiago Rebelo.

5.3 Future work

As mentioned at the introduction of this dissertation, the project management methodologies implemented on MECSE project were not the entire PM's methodologies range. There are disciplines which should be monitored during all phases of project. Considering the planning executed, further work is suggested aimed as defined below:

- Development and attachment on MECSE document "Project Charter" of Quality Management methodologies in order to ensure that the specifications are respected, and the final system is conform with the ESA standards;
- Perform a stakeholders analysis in order to understand if more partnerships are relevant for the development of MECSE project;
- Development of a responsibility matrix in order to establish the connections between the work performed and the team members;
- Development and implementation of Costs Management methodologies, and an assessment of costs for elaboration of a detailed costs sheet in order to establish the proper funding necessary for project completion;
- Assess the phase C of the project and detail further the activities displayed on WBS for a better understanding of the tasks that needs to be performed and for an accurate resources distribution;
- Development and implementation of an approval flow for the components produced;
- Draw and construction of the MECSE website, to publicise the project and get more UBI's students integrating the project.

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Annex A

A MECSE project charter

UNIVERSIDADE
BEIRA INTERIOR

PUSHING MOBILITY.

Project Charter

	NAME	SIGNATURE	DATE
Author:	Gonçalo Pardal		
Validation:	Jorge Monteiro		
Approval:	Tiago Rebelo		

Change log

Date	Updated Reference Number	change
22/08/2017	MCS-MAN-ProjectCharter-0009-0	First draft
24/08/2017	MCS-MAN-ProjectCharter-0009-1	Front page updated

Contents

1. Project charter purpose

This document defines the scope, objectives and general guidance for the implementation of the MECSE project.

It is a critical element and a single point of reference for the various phases of the project, emphasising on planning, implementation, monitoring and control and closure of the project, until a specific management plan is established.

This document is also the basis of the commitment between the Organization and the project management structure, serving, after its approval, as a formal authorization for the start of project execution, setting the objectives, budget, constraints, risks and resources allocation.

2. Executive summary

This document outlines the main guides of the project development, focusing on the following points:

- Main objectives:
  - Educational:
    - ➢ provide experience to Portuguese students and engineers on space projects;
  - Science:
    - ➢ Study the effects of an electromagnetic field on the plasma layer.

- Secondary objectives:
  - Technology:
    - ➢ Develop a MHD device for plasma layer manipulation;
    - ➢ Develop a modular structure for a CubeSat to be used in future space missions.

- Assumptions and constraints:
  - CubeSat 3U standard: CubeSat 3U configuration constraints both mass and volume. Therefore, the payload shall be designed with respect to those specifications;

  - ECSS standards: the ECSS (European Cooperation for Space Standardization) requirements must be considered;
  - Piggyback launch: MECSE nanosatellite will be launched as a secondary payload, so it will not be able to choose the orbital elements neither the launch date;
  - Budget: it is expected that the scientific and educational value of the mission could attract interesting collaborations and investments which would make this constraint less compelling.

- Main risks:
  - The payload is the most important subsystem since it influences all the subsystems which will be designed to support it. PL02 and PL03 will drive the system drivers such as power, mass and attitude;
  - The PLME will require the generation of an electromagnetic field during a short period. The require power will drive the Electrical Power System (EPS) design. Thus, it is important to find solutions that can minimize the peak power;
  - The scientific experiment shall be aligned with the velocity vector to minimize the error associated with the plasma measurements. Solutions that can achieve this requirement while minimizing the power consumption and mass must be identified;
  - The system's mass is constraint by the CubeSat configuration and by the payload's design. Thus, the subsystem's mass must be minimized;
  - Due to scientific reasons, it is required to perform the experiment in the lower altitudes possible where the ionospheric plasma starts to have similarities with the plasma found during atmospheric re-entry. Therefore, the orbital lifetime shall be decreased and solutions for a faster de-orbit must be studied. This parameter will impact the spacecraft lifetime;
  - As a scientific mission, MECSE will need to collect, store, and transmit a considerable amount of scientific data in a regular basis. Failure in transmitting the scientific data will compromise the mission success;
  - The Electromagnetic Generator (EMG) as well as the structure will be designed in-house which increases the risk of failure. Also, there is the risk of not be able to fit the experiment in a 3U configuration;
  - Subsystems shall consider COTS and flight heritage components as well as try to decrease the interfaces with other subsystems;

    - The project has limited funding, and so must consider educational opportunities and low-cost launch as well decrease the subsystems costs.

- Costs:
    - Materials and equipment – 66403,08 €
    - Project monitoring – 22665,6 €
    - Resources – 58992 €

- Schedule
    - The project starts on 04th January 2016 and is foreseen to finish on 09th January 2020.

3. UBI/ CEiiA's benefits

By executing this project, UBI will have the possibility to acquire real data on radio blackout event that occurs when an object re-enters the Earth atmosphere, helping the C-MAST research group validating the numerical model for plasma modulation.

CEiiA will acquire know-how on CubeSat standards and all the specific subjects present on a general satellite project and production, such as specific technical requirements and specific production quality standards.

4. Project framework

This project has born from the desire of students to get know-how on satellite development and at the same time have an active participation and cooperation with the industry. On this context, the MECSE project have been discussed to understand the possibility of performing some science experiment which could be valuable for the academic side (University of Beira Interior), to study the Radio Frequency (RF) Blackout and validate an in-house numerical method have been chosen.

Due to lack of means on university to fulfil the needs of a project with this dimension, was decided to find a partner capable of fill the gaps and share their knowledge. In this context, the partner is CEiiA, a product development centre located in Matosinhos, which became available to help UBI's students working to create an entire CubeSat.

Since the beginning was decided that most of the work will be performed by students, some at UBI's facilities, mainly the scientific side, that contemplates the validation of the numerical method to modulate the plasma and mitigate RF blackout and test the variables to understand the magnetic field generation needed to mitigate the RF blackout during re-entry on Earth atmosphere.

5. Scope

The current project encompasses the following work areas:

- Execution of engineering services, focusing on the complete development of a nanosatellite, at CEiiA's facilities;
- Validate the theoretical results about plasma modelling acquired by a science researchers at UBI;

6. Objectives

The MECSE project has the following objectives:

- Educational:
  - ➢ provide experience to Portuguese students and engineers on space projects;
- Science:
  - ➢ Study the formation of plasma surrounding the S/C when travelling in LEO;
  - ➢ Assess the effects of the S/C attitude motion on the plasma layer;
  - ➢ Study the effects of an electromagnetic field on the plasma layer.
- Technology:
  - ➢ Develop a MHD device for plasma layer manipulation;
  - ➢ Develop a modular structure for a CubeSat to be used in future space missions.

7. Assumptions and constraints

The MECSE project has the underlying assumptions and constraints:

- CubeSat 3U standard: CubeSat 3U configuration constraints both mass and volume. Therefore, the payload shall be designed with respect to those specifications;
- ECSS standards: the ECSS (European Cooperation for Space Standardization) requirements must be considered;
- Piggyback launch: MECSE nanosatellite will be launched as a secondary payload, so it will not be able to choose the orbital elements neither the launch date;
- Budget: it is expected that the scientific and educational value of the mission could attract interesting collaborations and investments which would make this constraint less compelling.

8. Project plan, deliverables and milestones

A detailed plan for the project execution is attached to this document on Appendix A, this chapter describes the main phases, deliverables and milestones.

8.1 Main phases

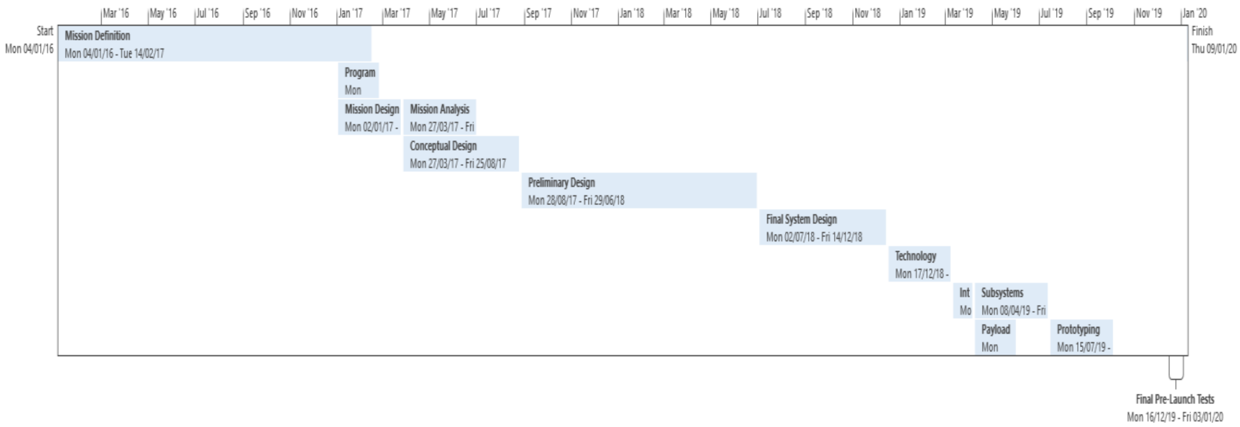

Figure A.1 MECSE project main phases.

8.2 Project deliverables

Table A.1 MECSE main deliverables list.

Responsible	Deliverable	Due date
CEiiA	CubeSat requirements report	30/06/2017
CEiiA	Equipment (payload and subsystems) report	14/12/2018
CEiiA	Mechanical development report	14/12/2018
UBI	Theoretical definition for scientific payload report	17/08/2018
CEiiA	Payload assembly	19/07/2019
CEiiA	Subsystems assembly	04/10/2019
CEiiA	Final assembly and delivery	01/11/2019
CEiiA	Final tests analysis, post-launch	01/02/2020

8.3 Milestones

Milestones are described on the following table:

Table A.2 MECSE project task list.

WBS	Task name	Due date
1.1.1	Mission definition	14/02/2017
1.1.2	Mission design	24/03/2017
1.1.3	Mission analysis	30/06/2017
1.1.4	Programmatics	24/02/2017
1.2	Conceptual design	25/08/2017
2.2.4	System preliminary design	29/06/2018
2.2.5	Payload Preliminary design	27/04/2018
3.1	Final system design	14/12/2018
3.2	Final payload design	16/11/2018
4.1	Subsystems prototyping	04/10/2019
4.2	Payload prototyping	19/07/2019
4.3	Final assembly	01/11/2019
4.4	System tests	13/12/2019
4.6	Final test	03/01/2020
5.1	Launch	09/01/2020

9. Project risks

The risk management will be present at every project phases, according to the Risk Management Plan shown on Appendix B, being that controlled and assessed periodically and/or when necessary.

The most important risks are the following:

Table A.3 MECSE project risks list.

# Risk ID	Phase	Risk Description	Consequences	Mitigation measures
1	B	Restrictions on mass, volume, and power budget applied by the CubeSat standards	If the restrictions will not be respected, the project could not accomplish successful its purposes	Apply the specific margins on each project phase to ensure the right accomplishment of the project
3	B	The PLME will necessitate a specific peak power to be performed	If the peak power will not satisfy the needs of the experiment, the scientific requirements will not be fulfilled	Ensure that the EPS will guarantee the peak power needed to run the experiment, apply a safety margin
4	E	The measurements of plasma should be as accurate as possible, so the environmental conditions should be more close to plasma layer at re-entry as possible	If this relation will not be considered, the values acquired by performing the experiment could be unrealistic	Perform the calculations and the characterization of the mission having this constraint well present
5	A	The mass budget should be conform with the CubeSat standards and with the ECSS standards	If the mass budget will not be respected, the project could be rejected or the launch costs could be highly increased	Ensure the right application of the standards on the preliminary phases and the right margins on each project phase
6	E	The satellite should be able to communicate with the ground on a regular basis to deliver the data gathered	If the satellite could not communicate with the ground station, the scientific data collected could not be accessed	Guarantee an alternative communication channel that could ensure the data transfer if the

			and evaluated	main communication system fail
7	C	Due to the in-house built of the satellite structure (unique concept), the likelihood of fail is bigger	If the satellite is launched with some structural fail, the probability of loss is greater	As soon as possible, in the detailed design phase, allow the prototyping and test for the entire structure to ensure is viability

10. Resources

10.1 Human resources

The human resources costs associated to the project are described on Appendix C.

10.2 Budget

The budget considered for a well succeed execution of the project is briefly presented below.

Table A.4 MECSE project budget.

	Overall
Acquisitions	
• Material and Manufacturing	
• Material	64603,08 €
• Manufacturing	1800 €
• Tools	40320 €
Global Expenses	
• Project monitoring	22665,6 €
• Transportation	9072 €
Human Resources	9600 €
Overall Costs	148060,68 €

11. Management

11.1 Project organisation

The graph below outlines the general project organisation by functional areas.

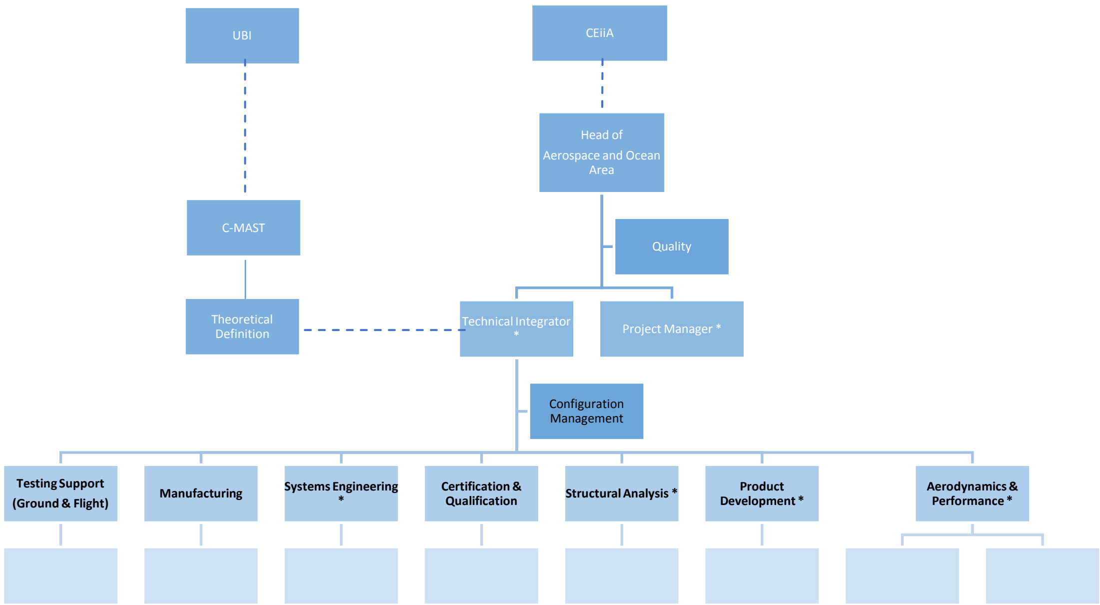

Figure A.2 MECSE organisational management.

* This sub-teams are the effective team members working at CEiiA's facilities.

11.2 Stakeholders and responsibilities

The stakeholders and its responsibilities for the project are:

- C-MAST (UBI research centre) - develop and validate the MHD numerical model, aiding in the design of re-entry objects;
- CEiiA - provide engineering and product development support, tools for project implementation.

12. Project Structure

12.1 PBS

The following diagram represents the Product Breakdown Structure (PBS) of the system:

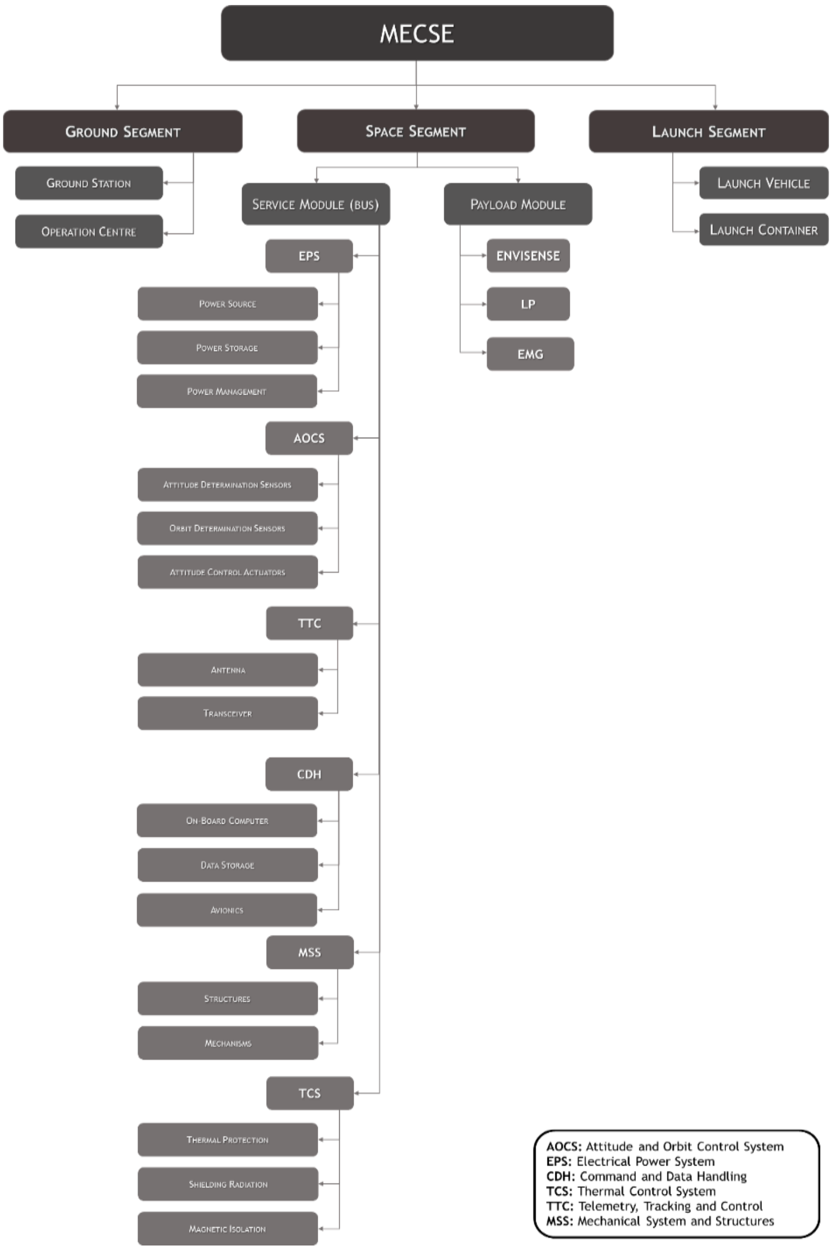

Figure A.3 MECSE project product breakdown structure.

12.2 WBS

The table below lists the various tasks to be performed during the MECSE project.

Table A.5 MECSE project work breakdown structure.

WBS	Task name
1.1.1.1	Needs identification
1.1.1.2	Mission characterization
1.1.1.3	Tradespace exploration
1.1.1.4	Mission Evaluation
1.1.1.5	Preliminary Risk Analysis
1.1.2.1	Mission statement
1.1.2.2	Mission objectives
1.1.2.3	Figures of merit
1.1.2.4	Mission requirements
1.1.3.1	Trajectory analysis
1.1.3.2	Mission lifetime
1.1.3.3	Communication access time
1.1.3.4	Eclipse time
1.1.4.1	Preliminary management plan
1.1.4.2	Preliminary systems engineering plan
1.1.4.3	Preliminary risk management plan
1.1.4.4	Preliminary cost management plan
1.1.4.5	Preliminary product assurance plan
1.2.1	Product tree
1.2.2	Assessment of system's feasibility
1.2.3	Preliminary risk and costs assessments
1.2.4	Allocate mission requirements to subsystems
1.2.5	Payload conceptual design
1.2.6	Definition of final mission concept
1.3	MDR
1.4	PRR
2.1.1	Updated technical requirements specifications
2.1.2	Preliminary design definition
2.1.3	Identification and definition of the external interfaces
2.1.4	Dedution of the lower-level requirements
2.2.1	Preliminary integration plan
2.2.2	Subsystems preliminary definition
2.2.3	Final technical plans
2.2.4	Preliminary design
2.2.5	Payload preliminary design
2.3	SRR
2.4	PDR
3.1	Final system design
3.2	Final payload design

3.3	Subsystems test and qualification
3.4	Technology assessment
3.5	Documentation update
3.6	Interface definition
3.7	Integration plan
3.8	CDR
4.1	Subsystems integration
4.2	Payload integration
4.3	Prototyping
4.4	Final assembly
4.5	System tests
4.6	Final pre-launch tests
4.7	Deployment for launch site
4.8	AR
5.1	FRR
5.2	Launch

12.3 Communication plan

The Communication Plan foresees the use of several communication channels, whose informative content must be objective, current, relevant and with the appropriate frequency to the correspondent phase of the project. The detailed information about the communication plan can be seen at Appendix D.

12.4 Information

The project information is available on CEiiA's network on the folder *Y:\Internships\Geral\MECSE Docs.*

12.5 Configuration management

The management of the technical information, as well as PBS, will be carried out within the framework of the Configuration Management Plan, shown on Appendix E.

13. Appendixes

Appendix A – Project plan

		Name	Duration	Start	Finish	Predecessors
1		**PHASE 0/A**	**430 days**	**1/4/16 8:00 AM**	**8/25/17 5:00 PM**	
2		**Mission Definition and Design**	**390 days**	**1/4/16 8:00 AM**	**6/30/17 5:00 PM**	
3		**Mission Definition**	**292 days**	**1/4/16 8:00 AM**	**2/14/17 5:00 PM**	
9		**Mission design**	**60 days**	**1/2/17 8:00 AM**	**3/24/17 5:00 PM**	
14		**Mission Analysis**	**70 days**	**3/27/17 8:00 AM**	**6/30/17 5:00 PM**	**9**
19		**Programmatics**	**40 days**	**1/2/17 8:00 AM**	**2/24/17 5:00 PM**	
25		**Conceptual Design**	**110 days**	**3/27/17 8:00 AM**	**8/25/17 5:00 PM**	**13**
32		PRR	0 days	8/25/17 5:00 PM	8/25/17 5:00 PM	31;30;28;27
33		MDR	0 days	3/24/17 5:00 PM	3/24/17 5:00 PM	9
34		**PHASE B**	**220 days**	**8/28/17 8:00 AM**	**6/29/18 5:00 PM**	**1;32**
35		**Phase B-1 Preliminary Design**	**55 days**	**8/28/17 8:00 AM**	**11/10/17 5:00 PM**	**32;31**
40		SRR	0 days	11/10/17 5:00 PM	11/10/17 5:00 PM	39;38;36;37
41		**Phase B-2**	**165 days**	**11/13/17 8:00 AM**	**6/29/18 5:00 PM**	**40**
47		PDR	0 days	6/29/18 5:00 PM	6/29/18 5:00 PM	45
48		**PHASE C**	**200 days**	**7/2/18 8:00 AM**	**4/5/19 5:00 PM**	**47**
49		Final system design	120 days	7/2/18 8:00 AM	12/14/18 5:00 PM	47
50		Final payload design	100 days	7/2/18 8:00 AM	11/16/18 5:00 PM	46;47
51		Subsystems test and qualification	100 days	7/2/18 8:00 AM	11/16/18 5:00 PM	43
52		Technology assessment	60 days	12/17/18 8:00 AM	3/8/19 5:00 PM	49;51
53		Documentation update	10 days	3/11/19 8:00 AM	3/22/19 5:00 PM	49;50;51;52
54		Interface definition	50 days	12/17/18 8:00 AM	2/22/19 5:00 PM	49
55		Integration plan	20 days	3/11/19 8:00 AM	4/5/19 5:00 PM	52;54
56		CDR	0 days	4/5/19 5:00 PM	4/5/19 5:00 PM	47;54;55
57		**PHASE D**	**198 days**	**4/8/19 8:00 AM**	**1/8/20 5:00 PM**	**48;56**
58		Subsystems integration	70 days	4/8/19 8:00 AM	7/12/19 5:00 PM	51;55;56
59		Payload integration	40 days	4/8/19 8:00 AM	5/31/19 5:00 PM	50;56
60		Prototyping	60 days	7/15/19 8:00 AM	10/4/19 5:00 PM	58
61		Final assembly	20 days	10/7/19 8:00 AM	11/1/19 5:00 PM	58;60
62		System tests	30 days	11/4/19 8:00 AM	12/13/19 5:00 PM	60;61
63		Final pre-launch tests	15 days	12/16/19 8:00 AM	1/3/20 5:00 PM	62
64		Deployment for launch site	3 days	1/6/20 8:00 AM	1/8/20 5:00 PM	63;65
65		AR	0 days	1/3/20 5:00 PM	1/3/20 5:00 PM	63
66		**PHASE E**	**1 day**	**1/8/20 5:00 PM**	**1/9/20 5:00 PM**	**57;65**
67		Launch	1 day	1/9/20 8:00 AM	1/9/20 5:00 PM	68

MECSE - page1

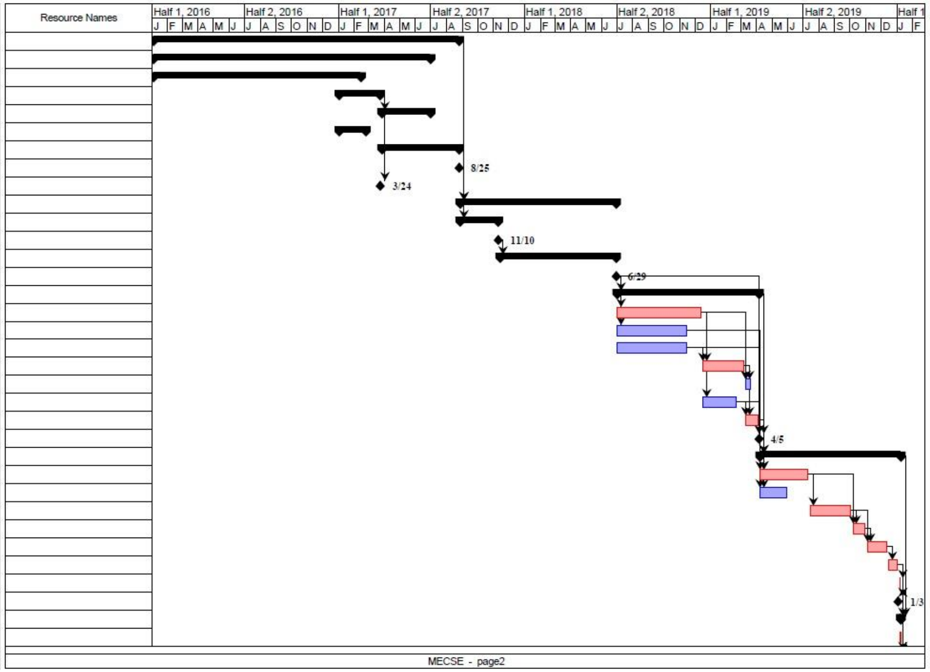

Figure A.4 MECSE project plan.

Appendix B – Risks management plan

Table A.6 MECSE project risks log (risks management).

Risks Log							
Activities/ Phase	Open date	Description	# ID	Impact on project	Close date	Mitigation measures	Mitigation Responsible
The origin of the risk	*Risk was found on:*	*Description of the risk*	*No. of risk*	*Changes/ impact on work*	*Risk was solved on:*	How to reduce and/or eliminate the risk	Person Responsible for eliminate/mitigate the risk
Phase B	20-07-2017	If the correct margins are not applied, mass budget may not be respected	1	Recalculation of the mass for all parts of the subsystems	11-08-2017	Apply at least 20% margin on preliminary definition and 5-10% on detailed definition. Due date: 16-08-2017	The responsible for each subsystem should ensure the application of mitigation measures recommended
Phase B	18-07-2017	Dificulty on predict the magnetic field on the specific distance of the center of the coil	2	Possible erros on the predicted values for the magnetic field		Validate the software values, need a formula to do it. Due date: 06-04-2018	Payload subsystem responsible
Phase B	10-08-2017	The PLME will necessitate a specific peak power to be performed	3	If the peak power will not satisfy the needs of the experiment, the scientific requirements will not be fulfilled		Ensure that the EPS will guarantee the peak power needed to run the experiment, apply a safety margin. Due date: 06-04-2018	The EPS subsystem responsible
Phase E	11-08-2017	The measurements of plasma should be as accurate as possible, so the environmental conditions should be more close to plasma layer at re-entry as possible	4	If this relation will not be considered, the values acquired by performing the experiment could be unrealistic		Perform the calculations and the characterization of the mission having this constraint well present. Due date: 05-04-2019	The Mission Analysis and Payload subsystems responsibles
Phase A	14-08-2017	The mass budget should be conform with the CubeSat standards and with the ECSS standards	5	If the mass budget will not be respected, the project could be rejected or the launch costs could be highly increased	11-07-2017	Ensure the right application of the standards on the preliminary phases and the right margins on each project phase. Due date: 25-08-2017	The responsible for each subsystem should ensure the application of mitigation measures recommended
Phase E	14-08-2017	The satellite should be able to communicate with the ground on a regular basis to deliver the scientific data	6	If the satellite could not communicate with the ground station, the scientific data collected could not be accessed and evaluated		Guarantee an alternative communication channel that could ensure the data transfer if the main communication system fail. Due date: 27-04-2018	The Communication and Data Handling subsystem responsible
Phase B and C	17-08-2017	Due to the in-house built of the satellite structure (unique concept), the likelihood of fail is bigger	7	If the satellite is launched with some structural fail, the probability of loss is greater		As soon as possible, in the detailed design phase, allow the prototyping and test for the entire structure to ensure is viability. Due date: 14-12-2018	Mechanic System and Structures responsible
Phase E	06-09-2017	The satellite should be able to communicate with the ground to understand its conditions and ensure the right orbit and other parameters	8	If the satellite could not communicate with the ground station, becomes an uncertainty if it still on its track		Guarantee an alternative communication channel that could ensure the tracking and control of the satellite. Due date: 14-12-2018	The Communication and Data Handling subsystem responsible
All phases	07-09-2017	Loss of knowledge, due to the replacement of a team member	9	If any of the volunteer participants of the project leave it and does not give any feedback about the work made or how to manage the tools adopted, the knowledge could be loss	15-09-2017	All the members that will leave the project soon should elaborate a report where they explain what they have done, how they did it and the future steps	Head of Unit
Phase B, C and D	13-09-2017	Mission cost too overwhelming to continue	10	If costs constraints were not respected, the project could be terminated due to its higher than maximum predicted costs		Guarantee a periodic review to the costs (past and future) to ensure that the project fits on its financing. Due date: 03-08-2019	Project Manager
Phase C	13-09-2017	Software interfacing with PLME delayed	11	If the software were not delivered in time, the project could suffer delays and loose the window of launch		Ensure that the teamworker assigned for the task will deliver the proper software in time. Due date: 29-06-2019	Payload subsystem responsible
Phase B and C	13-09-2017	PLME team does not provide documentation needed for MECSE design to continue in timely manner	12	A complete rethinking for the design could arise, provoking schedule delays and costs increase		Ensure a proper development of the PLME and its corresponding documentation. Due date: 23-02-2018	Technical Integrator

Appendix C - Preliminary budget estimation

Resource	Number of resource units	Price per Unit (€)	Allocation (%)	Hours of work (days*8)	Overall Cost (€)
Junior Engineer	1	10	10%	8392	8392
M. Sc. Student	3	0	100%	8392	0
Interns	10	0	50%	1056	0
Travel expenses	21000	0,36	100%	1	7560
Software Licenses					
CATIA license	3	10000	100%	1	30000
NASTRAN	1	3600	100%	1	3600
Production engineer	1	8	40%	3280	10496
Production	2	5	100%	800	8000

OVERALL (€)
68048

Overall With 20% Margin (€)
81657,6

Figure A.5 MECSE resource needs preliminary estimation.

Resource	Number of resource units	Price per Unit (€)	Overall Cost (€)
Consumables			
screws	100	0,3	30
rivets	390	0,04	15,6
Materials			
Aluminum	1	6,5	6,5
Titanium	1	41,8	41,8
Equipments			
Subsystems			53742
Machinery	60	25	1500

OVERALL (€)
55335,9
Overall with 20% margin (€)
66403,08

Figure A.6 MECSE production preliminary costs estimation.

Type	Cost (€)
Resources	81657,6
Production	66403,08
Launch *	0

Overall (€)
148060,68
Overall with 25% overhead (€)
185075,85

* The launch costs are assumed as zero at this point due to the objective of apply to ESA program which supports the costs of launch

Figure A.7 MECSE total costs estimation (resources plus production costs).

Appendix D - Communication plan

Table A.7 Communication management plan.

Communication Plan				
Type of communication	Periodicity	Location	Attendance	Meeting Objectives
Daily meeting	Every day	At the office	The team members working at CEiiA's facilities	Quick project status update
Weekly meeting	Every Friday at 12:00	On an appropriated room for the event	The team members working at CEiiA's facilities	Update about the work week and establishment of the future work
Monthly meeting	On the first Monday of the month	On an appropriated room for the event	The team members working at CEiiA's facilities plus the team members working at UBI's facilities	Complete update about the project status, including the challenges faced and possible solutions
E-mail reports	Every month		From team members working at UBI's facilities to PM	

Appendix E - Configuration management

Table A.8 MECSE project software list.

Software	Version	Use description
ProjectLibre	1.7	Software used to perform the schedule management, supported by automatic charts, providing a real time monitoring of the predicted work against actual work.
STK	11.2	Analysis of the communication access time between the ground station and satellite, analysis of the eclipse time, analysis of orbit (orbital elements).
DRAMA OSCAR	2.0	Satellite lifetime analysis considering different geomagnetic models.
STK Lifetime Tool	11.2	Satellite lifetime analysis.
CATIA V5	R20	Used to verify the suitability of new components, calculate the total mass, the centre of gravity location and the inertia properties. The main modules used on mechanical design were: Part Design, Assembly Design, Sheet Metal Design.
FEMM	4.2	Finite element package for solving 2D planar and axisymmetric problems in low frequency magnetics and electrostatics. This software assigns z to the axes of the abscissas and ordinates respectively.

Annex B

B Approval chain by subsystem

UNIVERSIDADE BEIRA INTERIOR

CEiiA PUSHING MOBILITY

<u>Approval Chain by Subsystem</u>

	NAME	SIGNATURE	DATE
Author:	Gonçalo Pardal		
Validation:	Jorge Monteiro		
Approval:	Tiago Rebelo		

Change log

Date	Updated Reference Number	Change log
16/08/2017	MCS-MAN-ApprovalChain-0003-0	First draft
21/08/2017	MCS-MAN-ApprovalChain-0003-1	Subsystem approval chain updated for a generic form
22/08/2017	MCS-MAN-ApprovalChain-0003-2	Added the validation grid
24/08/2017	MCS-MAN-ApprovalChain-0003-3	Front page updated

Each subsystem should have an approval chain to ensure the desired quality of the developed information.

Since the project is a university (educational) project in cooperation with the industry sector, the approval chain contains both sides on it.

The roles on the organisation, like Systems Engineer in Figure B.1, are identified with the acronym MhD due to represent a student. However, is considered engineer to associate his/her specific work to a real project worker.

At this moment, the approval chain is as follows:

Power

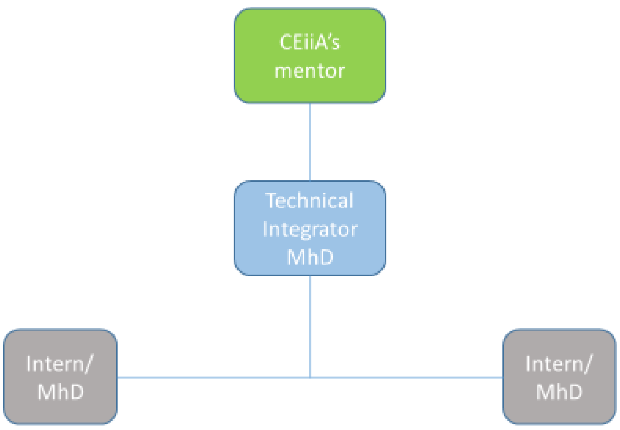

Figure B.1 Power approval chain.

Payload

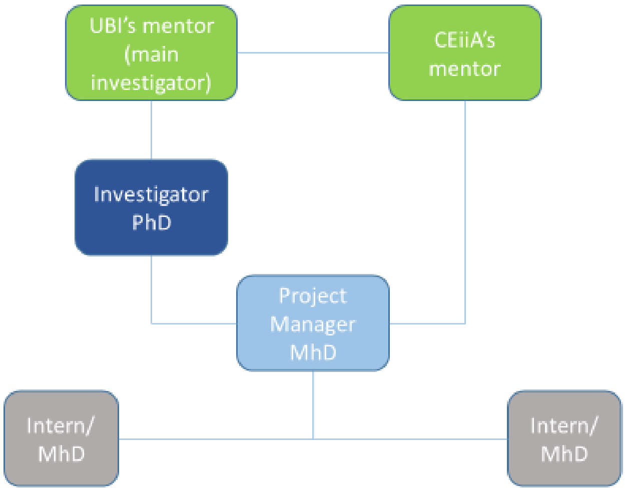

Figure B.2 Payload approval chain.

AOCS

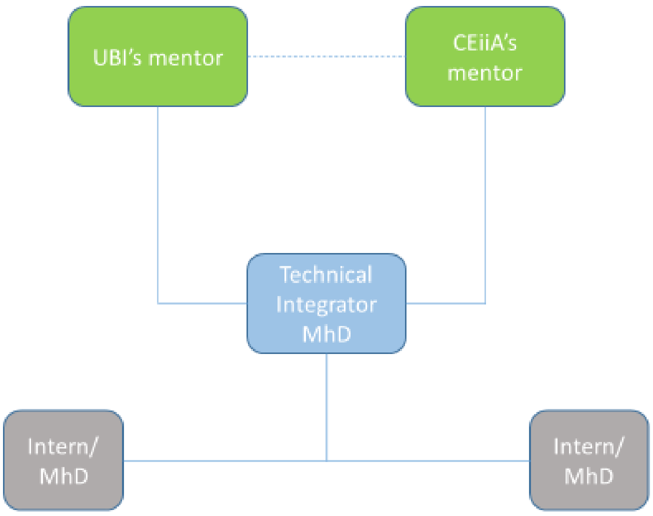

Figure B.3 AOCS approval chain.

Structures and mechanisms

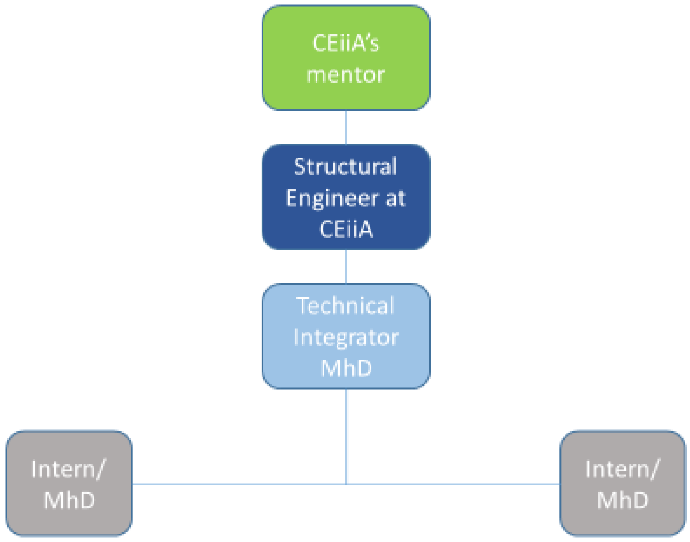

Figure B.4 Structures and mechanisms approval chain.

Communication and data handling

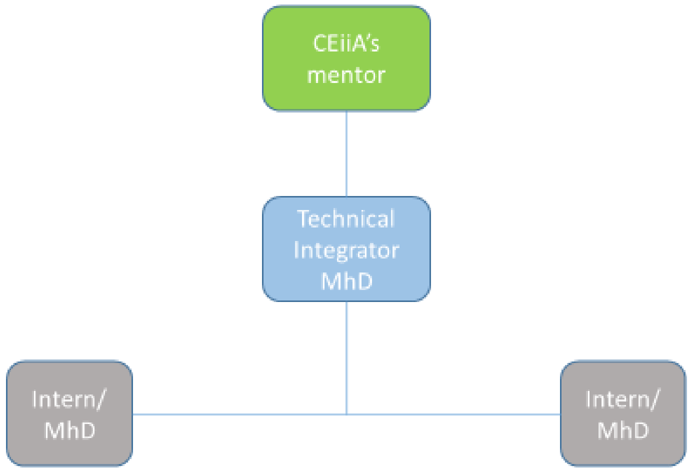

Figure B.5 Communication and data handling approval chain.

Mission analysis

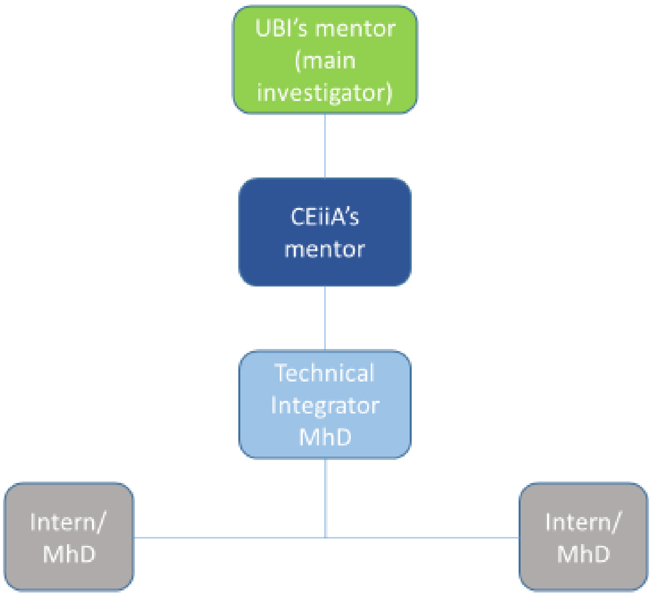

Figure B.6 Mission analysis approval chain.

Configuration

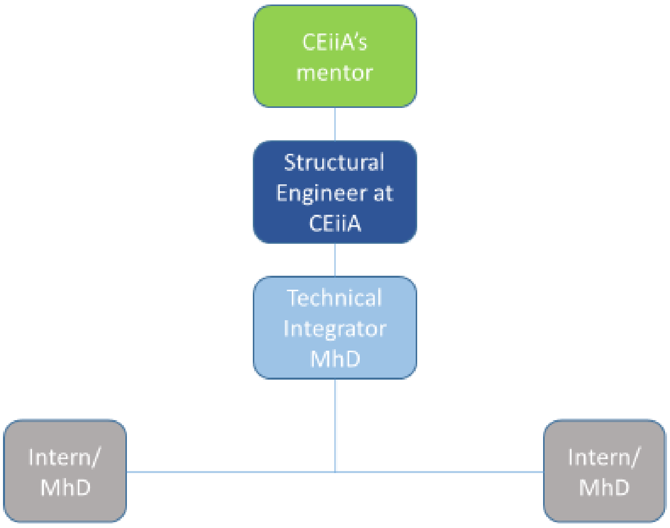

Figure B.7 Configuration approval chain.

Avionics

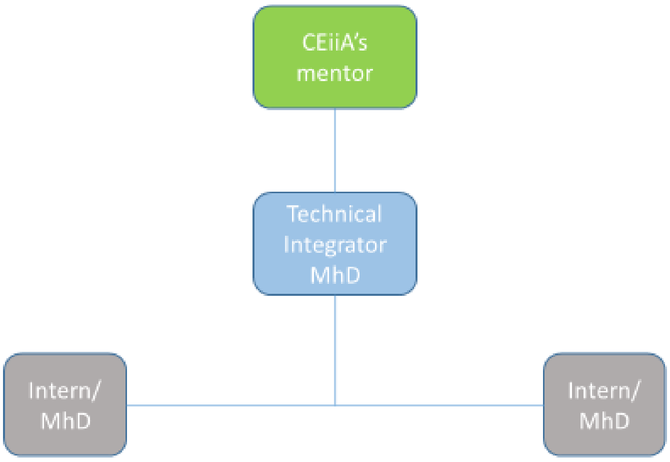

Figure B.8 Avionics approval chain.

Isolation

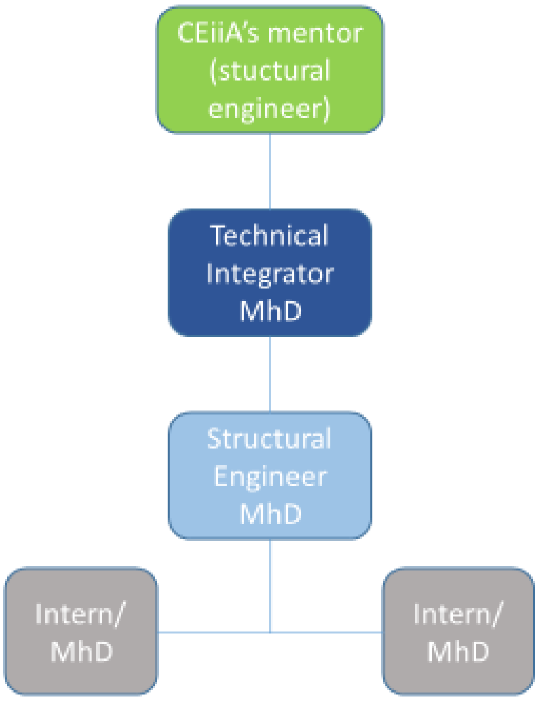

Figure B.9 Isolation approval chain.

Management

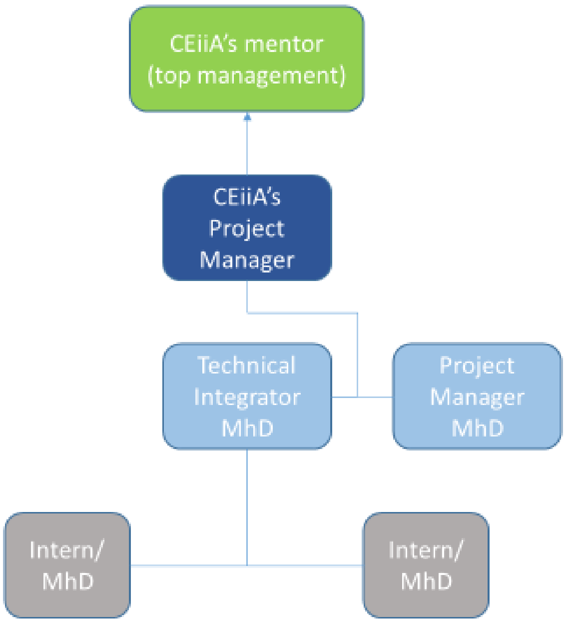

Figure B.10 Management approval chain.

Final note

The number of interns or MhD students allocated to these flows is representative, and may vary depending on the work load of each subsystem and MhD students availability.

Annex C

C File naming convention and document layout

UNIVERSIDADE BEIRA INTERIOR

CEiiA PUSHING MOBILITY

File Naming Convention and Document Layout

	NAME	SIGNATURE	DATE
Author:	Gonçalo Pardal		
Validation:	Jorge Monteiro		
Approval:	Tiago Rebelo		

Change log

Date	Updated Reference Number	Change
10/08/2017	MCS-MAN-FileNameConvention-0001-0	first draft
22/08/2017	MCS-MAN-FileNameConvention-0001-1	Added the validation grid, and its description on guidelines
24/08/2017	MCS-MAN-FileNameConvention-0001-2	Front page updated

The following convention will be used for naming all files related to the MECSE project:

(project name)-(subsystem)-(brief descriptor)-(document number)-(version)

For example:

MCS-PL-PrototypeCalibration-0201-1

Project name

MCS: Common to all MECSE project documents.

Subsystem

A two-to-four letter code for the name of the subsystem generating the document.

Table C.1 MECSE project document naming reference number list.

Subsystem	Abbreviation	Reference Numbers Beginning
Management	MAN	0000
Mission Analysis	MR	0100
Payload	PL	0200
Electrical Power System	EPS	0300
Mechanic System and Structures	MSS	0400
Thermal and Magnetic Isolation	TCS	0500

Attitude and Orbit Control System	AOCS	0600
Communications and Data Handling	COMM	0700
Configuration	CONF	0800
Systems Engineering	SYS	0900
Miscellaneous	MISC	1000

Brief description

A short (< 3 words) description of document contents, written in camel case, without spaces. Camel case means using a capital letter for the first letter of every words and no spaces between the words.

For example:

ElectronicsInterface

SubsystemDefinitionDocument

The only non alpha-numeric character permitted in file names is a hyphen "-"

No spaces are permitted in file names

Document number

Each document has a unique number which is generated from an incrementing list kept locally by the documentation manager.

To find the correct number for your new document go to the list, add your document file name and title to the list and assign it the next number in the sequence.

If someone is updating an older document keep the document number but update the version. Add the new document file name on library (ie. With "-2" at the end to indicate the 2nd version etc.) and enter the updated reference code. It is forbidden to delete earlier versions.

Version

The final element of the document number is the document version number. Starting at 0 for a draft of a document and 1 for the initial issue version then incrementing up for subsequent issues.

Title of document

The title of the document should be a clear, concise description of the work contained in the document.

Document header

The header should be formatted in 3 columns (as seen in this documents' header) as follows:

(name of institution)	(name of project)	Ref:
		Date:

Name of institution

The institution in this case will be "University of Beira Interior/ CEiiA"

Name of project

The project is "MECSE"

Reference code

The reference code is the file name (including version).

Date

Document date must be issued in "dd/mm/yyyy" format.

Document footer

The footer should contain the page number aligned on the right side of the page, in "X of Y" format.

Change log

All documents will have a "Change Log" on the first page. This is a table where any change made to the document will be logged stating the date, a brief description of what was changed or added, and the updated reference number. (The reference number is updated by incrementing the final number by 1 each time a new version is issued.)

For each new version, the new reference number should also be logged in the table on the digital library (in development). It is forbidden to delete previous versions.

Validation table

Each document should present a table on front page, respecting the guidelines defined for MECSE project, which states that each document should be validated and approved by different people, after being typed.

Font

All documents will be written in the “Arial” font. Main body text should be size 12 and titles should be size 14, bold.

Titles and headings

The main document title should be centred, size 14, bold and underlined.

Sub headings throughout the document should be left justified, size 14, bold but NOT underlined.

Header and footer typing settings

Header and footer should be written in the “Arial” font, size 10, with the orientation previously displayed.

Document margins

The document margins should be “Moderate” margins (which means: 2.54cm top and down, and 1.91cm left and right side).

Paragraph settings

All the common text should be justified and all the document should have 1.5 lines of line spacing without any space before and after (0 lines).