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The ESEO Assembly Integration and Verification (AIV) Plan

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Abstract

In the development of a space program many are the documents that must be delivered for every mission review: starting from phase B, when the system requirements and the preliminary design are defined, until the launch campaign in phase E when the commissioning of the satellite is done.

In this work two documents related to the B2 phase of the European Student Earth Orbiter (ESEO) project are presented. The Design and Development Plan (DDP) describes with reference to the phases B2, C, D and E1 of the project life cycle the approach, the processes, the methods and facilities chosen for the overall project execution. The Assembly Integration and Verification (AIV) Plan describes integration, assembly, test organization, test description and test control during the project. The aim is a logical integration and test flow where critical aspects are analyzed early in the scheme, whereas non-critical issues are checked at a higher level to increase efficiency and eliminate redundant operations in the process.

Keywords: The European Student Earth Orbiter (ESEO), Design and Development Plan (DDP), Assembly Integration and Verification (AIV) Plan, AIV hybrid approach.

Sommario

Durante lo sviluppo di un progetto spaziale è molteplice la documentazione prodotta al fine di tenere traccia di tutti i passaggi che vanno dall'analisi preliminare della missione fino alla messa in orbita del satellite. Vi sono più fasi nel corso del processo, ciascuna caratterizzata dal raggiungimento di determinati obiettivi e dal consolidamento di alcune parti del progetto.

Questa tesi presenta una parte della documentazione sviluppata nel corso della fase B2 del progetto ESEO, the European Student Earth Orbiter. La parte del Design and Development Plan (DDP) descrive a livello di sistema e per tutti i sottoelementi l'approccio, i processi, i metodi e le infrastrutture selezionati per l'esecuzione del progetto. L'Assembly Integration and Verification (AIV) Plan contiene, invece, la selezione delle porcedure di verifica e test da eseguire a tutti i livelli. La descrizione e il controllo dei test, l'assemblaggio e l'integrazione vengono al suo interno specificati affinché il flusso di lavoro sia strutturato in maniera efficiente: aspetti critici nello schema di lavoro vanno analizzati presto nel procedimento, mentre funzioni meno critiche vengono verificate solo ad alto livello per evitare operazioni ridondanti.

Parole chiave: The European Student Earth Orbiter (ESEO), Design and Development Plan (DDP), Assembly Integration and Verification (AIV) Plan, AIV approccio ibrido.

1 Acronyms

AIT	Assembly Integration and Test
AIV	Assembly Integration and Verification
AOCS	Attitude and Orbit Control System
CDR	Critical Design Review
CGS	Carlo Gavazzi Space
DDP	Design and Development Plan
ECSS	European Cooperation for Space Standardization
EEM	Electrical Engineering Model
EGSE	Electrical Ground Support Equipment
EM	Engineering Model
EPS	Electrical Power Subsystem
ESA	European Space Agency
ESEO	European Student Earth Orbiter
FAR	Final Acceptance Review
FDS	Flight Dynamic System
FM	Flight Model
GS	Ground Station
GSE	Ground Support Equipment
HW	Hardware I/F Interface
LEOP	Launch and Early Operation Phase
LRR	Launch Readiness Review
MAIT	Manufacturing, Assembly, Integration and Test
MCC	Main Control Center
MDR	Mission Definition Review
MGSE	Mechanical Ground Support Equipment
MPS	Mission Planning System
OBDH	On Board Data Handling
OGSE	Optical Ground Support Equipment
PDR	Preliminary Design Review
PFM	Protoflight Model
P/L	Payload
QM	Qualification Model
QR	Qualification Review

S/C	Spacecraft
SRR	System Requirement Review
S/S	Subsystem
STM	Structural Thermal Model
SW	Software
TCC	Test Control Computer
TCS	Thermal Control Subsystem
TM/TC	Telecommand and Telemetry
VP	Verification Plan

Table 1.1: List of acronyms

2 The AIV Approach

This chapter counts as guideline of procedures for the definition of an assembly integration and verification plan of a space programme. The sections that follow give an overview of the methodologies described in the *European Cooperation for Space Standardization (ECSS)* for the selection of a specific AIV approach. In the second part of the chapter other AIV proposals are presented.

2.1 Scope

For the development of a satellite or more of a space programme, in order to successfully satisfy all the desired requirements and specifications, it is necessary to develop and apply an adequate verification and test campaign. Hence an accurate selection of verification and test procedures must be done for a successful AIV plan. The selection regards integration, assembly, test organization, test description and test control which must be specified to explain the rationale behind. The aim is to come to a logical integration and test flow where critical aspects are analyzed and possibly tested early in the scheme, whereas non-critical issues are checked at a higher level of integration to increase efficiency and eliminate redundant operations as much as possible [1].

To describe and follow the project in each step, an appropriate documentation must be prepared so that mistakes can be avoided in the crucial phases of a project's life cycle.

2.2 ECSS Guideline

2.2.1 Model philosophy

The test baseline in a space program results directly from the choice of the project model philosophy. The main idea of this approach is to define an optimum number of physical models required to achieve the necessary confidence in the product verification with the shortest planning and the best weighting of costs and risks.

Sometimes, depending on the adopted philosophy, test activities are shared among different models. This sharing depends on model philosophy, project characteristics and model representativeness.

The ECSS defines the following project model philosophy situations [2]:

1. Prototype approach
 - a) The qualification testing can be conducted on one or more qualification model (QM), according to the project requirements and objectives, always with qualification test levels and duration.

- b) For tests on more than one QM, the tests shall be performed on the different models according to their representativeness (e.g. functional qualification is performed on EQM) and the test sequences for each model shall be adapted accordingly.
- c) The flight model (FM) shall be subjected to complete acceptance testing.

2. Protoflight approach

- a) All the qualification tests shall be performed on the same model to be flown, normally with qualification test levels and acceptance test duration.
- b) The protoflight model (PFM) should be subjected to a test programme defined on a case-by-case basis. The test program combines both qualification and acceptance tests to satisfy the qualification and the acceptance objectives. In this situation the know how of specialists and the involved company play a fundamental role.

3. Hybrid approach

- a) A combination of the prototype and protoflight rules shall be applied.
- b) Specific qualification testing in the critical areas can be conducted on dedicated models (e.g. structural thermal model (STM) or others).
- c) The acceptance testing shall be performed only on the PFM with specific test levels.

Nowadays all three presented approaches can be found in the space industry.

The prototype scheme is for example applied in the development of constellations. A qualification model is built and on the basis of test results, all other elements of the formation can be then constructed and subjected only to acceptance testing. This philosophy is normally adopted for communication and navigation programs. Other fields where the prototype model is built, for reliability and security reasons, is the military industry.

The protoflight philosophy was instead used in the development of the first educational mission: SSETI Express. This development choice is often determined by a low budget availability and when timing is tight.

Hybrid philosophy combines more or less the advantages of the previous methodologies. It offers a good balance of costs and timing while guaranteeing the necessary product quality. This is the approach selected for ESEO, as it is presented in chapters 4 and 5.

A last example that combines all approaches is the Columbus module of the International Space Station (ISS) [15]. Its system development, integration and test programme had a hybrid approach. The model philosophy at unit level instead reached from dedicated qualification models to the protoflight approach, depending on the complexity of the items. A system-level engineering model did not exist. Columbus functional qualification was performed on the Electrical Test Model (ETM) and/or on the Protoflight Model (PFM), supplemented by analyses and demonstrations on mock-ups.

2.2.2 Testing approach

Test programs are an essential part in a space project's life cycle to ensure that the product, each of its part, achieves all the design, performance and quality requirements [2].

Starting from the design requirements, indicating the expected performance and the condition under which the element shall operate, the basis for test planning, requirements and criteria are drawn. Each entity, at level project levels, must indicate the intended verification method: a verification matrix is so created containing the selected verification methods for every single item. Starting from this matrix an equivalent test matrix can be defined which contains the detailed types of tests each item must pass.

The test plan shall contain the following aspects:

- describe and sequence all tests;
- define the objectives and justify the scope of the tests;
- indicate the test facilities to be used;
- control the execution of all tests.

Testing level	Description
Development	Development testing are used to support the design feasibility and assist in the evolution of the design. They are used to validate new design concepts and the application of proven concepts and techniques to new configurations.
Qualification	Qualification testing are used to demonstrate that the design implementation and manufacturing methods have resulted in hardware and software conforming to the specification requirements.
Acceptance	The purpose of acceptance testing is to demonstrate conformance to specification and to act as quality control screens to detect manufacturing defects, workmanship errors, the start of failures and other performance anomalies, which are not easily detectable by normal inspection techniques.
Proto-flight	The protoflight approach presents a higher risk than the prototype approach in which design margins are demonstrated by testing on a dedicated qualification product. In this case however all tests are executed on the same item. A strategy to minimize the risk can be applied by enhancing development testing by increasing the design factors of safety.

Table 2.1: Testing Levels

Normally during tests the order in which environments are encountered shall be respected. Another fundamental aspect in the test execution is the early identification of potential failure zones and defects on the manufactured object.

The test approach often differs between elements. These diversities depend from the item characteristics, as for example the design maturity, the qualification status of the object or also the model philosophy. As well cost and acceptable risks are pondered differently in accordance with the selected project's philosophy.

In a structured test campaign different test phases are foreseen, applied at different stages and levels in accordance with the verification process. The ECSS follow the sequence reported in table 2.1.

In the flow of events the start of a new verification and test stage is only allowed after having successfully completed the prior stage. The preferred approach is always bottom-up, which means tests are executed from the equipment up to the segment entity.

Generally before proceeding with qualification a development phase shall be executed to demonstrate feasibility of the desired element. All new design concepts must be at this stage verified as well as new configuration techniques of proven items. After the successful suitability check all necessary design improvements must be applied prior to the initiation of the flight element manufacturing. If the test of a single entity is not feasible, a combination of them, with the support of analyses and simulations, can be tested.

Some examples of the afore mentioned test levels in table 2.1 for the different design stages are presented in chapter 5 of this work. Qualification and acceptance test levels and durations are presented in tables 5.1 and 5.2. For the protoflight tests a combination of these is applied: normally qualification levels are applied but in relation to acceptance durations. For development testing a case by case approach is instead selected.

2.2.3 Verification approach

2.2.3.1 Verification objectives

The objective of the verification process is to demonstrate, that the product meets the specified requirements. The main aspects of this process are listed below [3]:

- it has to demonstrate that design and performance meet the specified requirements at the specified levels of confidence;
- it has to ensure that the product respects the qualified design, is free of workmanship errors and therefore ready for use;
- it has to confirm product integrity and performance ability for all phases of the project life cycle: launch, commissioning, specific mission events, etc;
- it has to confirm that the overall system is able to fulfil the mission requirements.

The verification process activities consist of planning, execution, reporting, control and closeout as reported in the diagram flow below.



Figure 2.1: Verification activities

Each step and implementation activity is documented by means of a specific set of verification documents presented in table 2.3.

Document name	Abbreviation
Verification Plan	VP
Assembly, integration and test plan	AIT plan
Assembly, integration and verification plan	AIV plan
Verification control document	VCD
Test specification	TSPE
Test report	TPRO
Analysis report	ARPT
Review of design report	RRPT
Inspection report	IRPT
Verification report	VRPT

Table 2.2: Documents for Verification

In some cases VP and the AIT Plan can be combined in one single document: the AIV Plan. In this case VP and AIT plans do not exist anymore as single entities.

2.2.3.2 Verification planning

To achieve the verification objectives a verification approach must be established in the early phases of a project. The approach should be defined on the basis of the mission's requirements and the following aspects should be considered:

- design constraints;
- qualification status of candidate solutions (product category);
- availability and maturity of verification tools;
- verification (including test) methodologies;
- ground segment and in orbit constraints for the in-orbit stage (including commissioning);
- programmatic constraints;
- cost and schedule.

Generally in defining the verification approach, the following questions should be answered:

- “*What* are the products and requirements that must be submitted to the verification process?”
- “*How* can they be verified? Which verification methods should be adopted?”
- “*When* can the chosen verification strategy be applied?”

These steps are normally conducted in an iterative process ensuring that the approach is agreed by both the supplier and the customer.

For verification several methods can be applied: singularly but also combination of them are allowed and in some critical cases requested. Table 2.4 shows the order of precedence that normally provides more confidence in the results.

Generally testing is the preferred verification method because it allows an accurate observation of the element’s behaviour. Due to possibly growing costs an accurate selection in the test program shall be done to identify all cases which really need tests.

Test method	Description	Example
Test	Verification by test shall consist in measuring product performance and functions under representative simulated environments.	Shaker, Acoustic chamber, etc.
Analysis	Verification by analysis shall consist in performing theoretical or empirical evaluation using techniques agreed with the Customer. These techniques comprise systematic, statistical and qualitative design analysis, modelling and computational simulation.	Esatan, Nastran, STK, etc.
Review of design	Verification by Review-of design (ROD) shall consist in using approved records or evidence that unambiguously show that the requirement is met. Approved records can be design documents and reports, technical descriptions, and engineering drawings.	With official reports the design is verified, etc.
Inspection	Verification by inspection shall consist in visual determination of physical characteristics.	Visual verification

Table 2.3: Verification methods

In the verification process the verification is performed at different product decomposition levels. The number and type of verification levels depends upon the complexity of the project and on its characteristics. In most cases the identified verification levels for a space product are showed in figure 2.1.

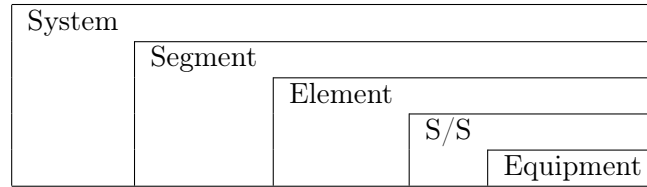


Figure 2.2: Verification levels

Subsequent verification stages divide the overall verification process along the project life cycle. To pass on to the successive stage the previous stage must be closed successfully. Each stage can vary depending on project characteristics. The verification stages are qualification, acceptance, pre-launch and in-orbit, including commissioning. In some cases also a post-landing stage is previewed if the reentry of the space vehicle is foreseen for a particular mission.

In the verification process definition the tools to be used to perform verification and testing activities are identified and their procurement and utilisation are planned. In some cases tools are themselves subjected to formal verification and therefore testing before allowing their operation.

2.3 Alternative Solutions

In the past decades other solutions have been investigated to possibly find a different approach to space element AIV processes. Some of them are presented in the next paragraphs.

2.3.1 Optimum - AIV

The size and complexity of tasks for the establishment of an AIV plan of a space project always showed the necessity of efficient and flexible planning and scheduling tools [8,9]. In 1988 ESA commanded a study to a consortium to find a solution to the described problem. The developed planning tool assists the AIV team at all levels during phases B and C/D. In the first phase a preliminary high level plan is drawn which is refined and detailed in the successive phases. Optimum-AIV is a dynamic environment in which each planned activity can be reorganised through an appropriate artificial intelligence (AI) based planning technique. In phases C and D Optimum-AIV refines and monitors planned activities. In case of problems it assists the user in the identification and in the solution and eventually in the establishment of a new flow of work.

Optimum-AIV provides the following facilities:

- definition of AIV plans from a preliminary draft to the final complete version;
- development of plans and schedules at all levels of the project;

- it provides assistance in failure detection and consequent replanning of project activities. The assistance in replanning using knowledge based techniques is the primary objective of the Optimum-AIV.

This planer has its origins in the early 90s and has been developed at the Artificial Intelligence Applications Institute (AIAI) at the University of Edinburgh. At the current time Optimum-AIV is in use by the European Space Agency for AIV planning activities for the Ariane rocket payload bay [10].

2.3.2 The Model and Test Effectiveness Database (MATED)

The desire to fasten space activities without compromising the product's quality is growing more and more. The objective still remains the mission's success while reducing development costs and time. The AIV process is consequently involved since it constitutes normally 20 – 30 % of the costs and up to 60 – 70 % of the schedule. All decisions concerning model, test and verification philosophies are therefore important cost drivers for a project life cycle.

Since the existing standards are mostly based upon tradition and on empirical data they shall be improved in relation to updated test-effectiveness parameters. That is why ESA in 2001 commanded a study which objective was the establishment of the MATED [7]. The database includes AIV plans, non-conformance reports (NCR) and flight anomaly (FA) data. All these information are shared and available for space agencies, space companies and the overall space industry. The idea of sharing arises since the initiative, if promoted by only one entity, would not allow the collection of enough study cases to provide statistically significant results. In the end the database shall count as a resource for a continuous improvement of the AIV approach and all related concepts. Figure 2.2 shows the logic scheme of the database.

The main functions of the MATED are:

1. collect and archive all possible data from different missions about anomalies occurred during ground and flight operations and tests;
2. collect and archive AIV processes of different missions paying particular attention at the most expensive activities;
3. through the collected data provide analyses results to improve both test effectiveness and AIV programmes;
4. ensure the exchange of the data above through a secure and controlled scheme.

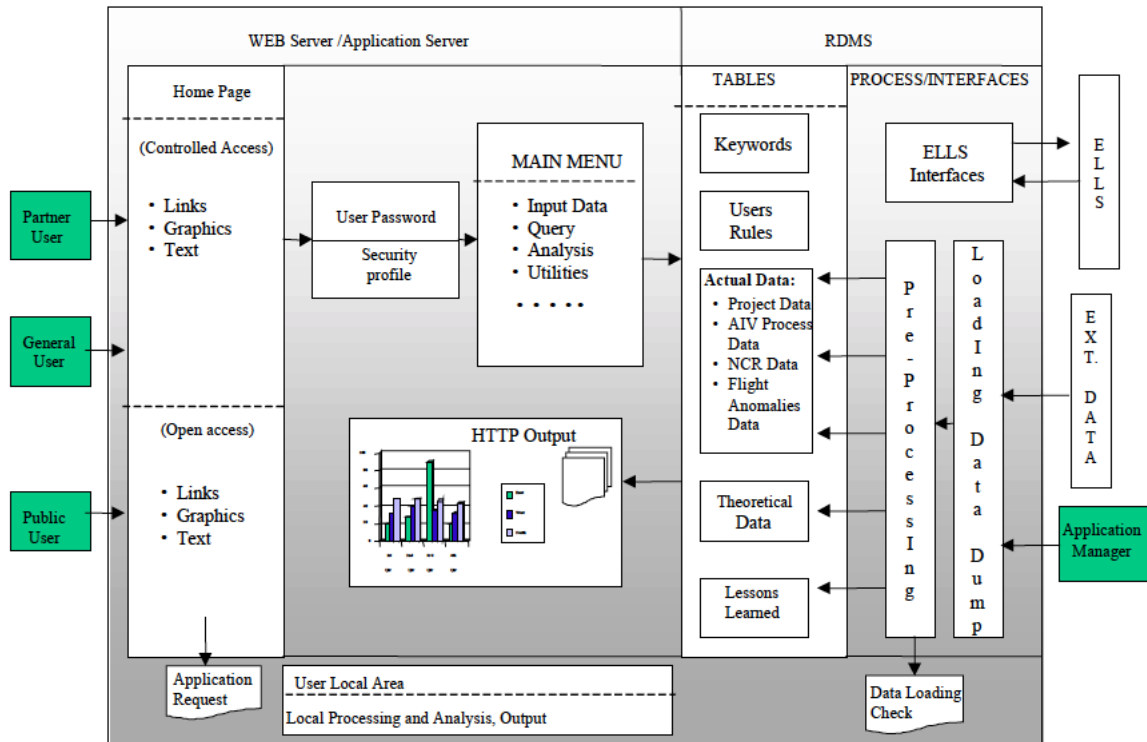


Figure 2.3: MATED Logical Design

The analyses executed with the data included in the MATED shall allow comprehension of many doubts and aspects. Below only some questions are listed to whom an answer may be given.

- Which tests and when in the development cycle result in more NCRs?
- What are the S/S that result to be more critical during test activities?
- For a certain item, does an alternative verification method exist which could be more effective?
- Which actions in the AIV process are mostly contaminated by workmanship errors?
- How can we compare two different model and consequent test philosophies?
- Which is the most vulnerable S/S or P/L during operations?

In the end the rationalisation of both model and test philosophies for future space projects within Europe is a decisive aspect: on one hand costs and scheduled activities must be reduced, on the other hand the quality of space products cannot be compromised and efficient risk mitigation plans must be developed. To achieve this intent a sharing politic of know-how concerning AIV processes was established through the MATED. The more agencies and companies participate, the more data for successful analyses will be available. The initiative aims at providing reciprocal benefit for all participants.

2.3.3 The Project Test Bed (PTB)

Along space projects a great number of simulation and test facilities must be used: for mission analysis, design and development, AIV processes and flight operations preparation and training. EGSE are normally used to verify the spacecraft's functionality. Simulators instead are developed to support design feasibility studies of elements during the various phases of the project. In these cases different requirements at different stages imply that simulators often are setup for specific analyses with no possibility of reuse.

The PTB aims at reducing the effort in the design, development and verification processes. It consists mainly in the establishment, early in the project life cycle, of an adaptive simulation infrastructure. This entity can then evolve with the project through all its phases [4,18]. The PTB is therefore a facility that can include specific components for a particular project phase or mission, but can also work transversely on different phases or even other missions (figure 2.3)

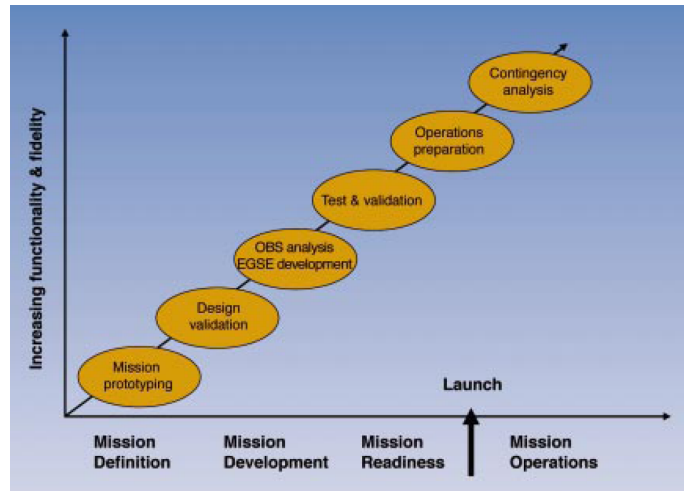


Figure 2.4: Evolution of the PTB

The PTB is composed by three main parts (figure 2.4):

1. The real-time simulator. It contains models of the spacecraft, its subsystem, the environment and of the ground segment. Simple models at the beginning can then evolve during the project's life cycle in accordance with the change of performance requirements. The aim is to assist and refine the mission concept and the system design. In further steps verification and validation operations are also possible.
2. The EMCS, EGSE and Monitoring Control System, which is responsible for telemetry and telecommands, consists of a test control computer (TCC) and a dedicated suite for test and operational procedures.

3. The third part is a hardware (HW) emulator which runs the spacecraft's on-board computer software (SW).

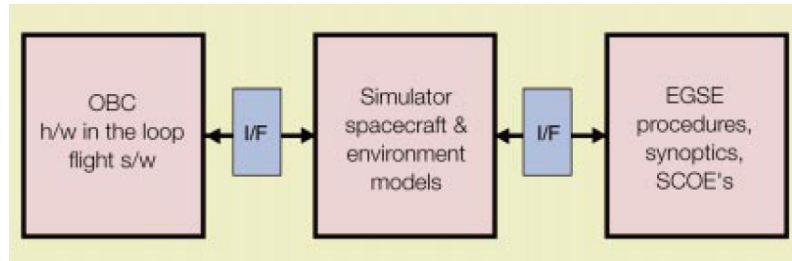


Figure 2.5: PTB Concept

An important aspect is that some elements are developed so that they may be reused on similar missions.

At the beginning of a project, the prototype concept is always created through components of other projects. In later phases each component is then specified and developed, both SW and HW, in all of its parts with the necessary accuracy and can be added with minimal impact on the PTB simulator.

The PTB is so the first step in the definition of a reusable simulator architecture to support spacecraft design.

At the present time the PTB approach has been used to support the spacecraft design phase of three missions:

- PROBA-1
- The Land mission (only feasibility study)
- SMART-1 [17]

2.3.4 The Simulation Model Portability (SMP)

A further step after the PTB idea is the Simulation Model Portability (SMP) project [5]. ESA has always been involved in space simulation developments, and is developing simulations for a variety of applications as for example analysis, engineering, test and validation, operations preparation and training. Each simulator is normally developed by a different group during different stages within a space project. In order to decrease the overall simulator development cost within a space project, ESA has commanded and is leading the development of the Simulation Model Portability (SMP) program. The SMP shall enable reuse and portability of simulation models within the same space project as well as across projects, thus contributing to reduced overall costs.

The first release of SMP is dated 2001. This version was successfully applied to a number of simulator developments within ESA projects but a second release, SMP2, is already under progress [19].

In 2006 the ECSS comitee started promoting the SMP2 specification to become part of the ECSS series of standards. This work is currently on-going and the plan of the working group together with the European space industry is to have an approved standard within 2010.

SMP is based on the ideas of component-based design and on the open standards of unified modeling language (UML). One of the basic principles is the separation of the platform specific and platform independent aspects of the simulation model. This protects the development of the model from changes in technology by defining the model in a platform independent way, which can then be mapped into different technologies. Furthermore the SMP specifications provide standardised interfaces between the simulation models and the simulation run-time environment for common simulation services. Inter-model communication will be supported as well. The SMP standard has already been applied to:

- Rosetta
- Mars Express
- Galileo Programme

2.4 Conclusion

In the establishment of the AIV plan for the ESEO mission no industrial tool has been adopted. The final structure of the DDP and AIV plan are the result of years of space working experience of Carlo Gavazzi Space (CGS) and rely basely upon ECSS guidelines.

For European space companies it would be certainly a common benefit to have alternative well proven and qualified methodologies in the approach of a space project but for the moment ECSS standards remain the main procedure to follow.

3 ESEO

3.1 The ESEO Programme

ESEO, the *European Student Earth Orbiter*, is the second mission within ESA's Education Satellite Programme after SSETI Express launched into LEO in 2005. The project is currently at the end of Phase B2 and it builds upon the experience gained in the previous mission. At the present time about 100 students are actively involved from 13 universities across all Europe.

The ESEO spacecraft is being developed to be launched into Low Earth Orbit (LEO) in 2012. The exact launch opportunity has yet to be confirmed, although ESEO is candidate for launch with one of the VEGA VERTA flights. However, to increase the mission's flexibility and robustness the design aims at preserving adaptability to other launch vehicles. In orbit the spacecraft will perform its payload operations over a period of six months, with the possibility of a mission extension. The orbit will be Sun synchronous, and the remaining orbit parameters (maximum altitude < 600 km) are selected so that the natural orbital drag will ensure re-entry within 25 years, thus complying with the European space debris code of conduct. Natural orbital drag will be used since no propulsive system is installed on board.

Carlo Gavazzi Space (CGS), as Industrial System Prime Contractor, is managing the ESEO project and in coordination with ESA they provide technical support to the university student teams during the execution of their part of the project. The students obtain training and benefit from access to the CGS and ESA in-house expertise, and will use industry and ESTEC facilities for spacecraft assembly, integration and testing.

The student teams are expected to provide most of the spacecraft subsystems, payload and ground support systems in coordination either with their universities or European space industries in order to deliver their elements of the mission as part of their academic studies [16].

3.1.1 University Student Teams

The universities listed in table 3.1 throughout Europe and Australia are at the present time involved in the ESEO project, coordinated by the prime contractor CGS.

University/Organization	Subsystem/Payload
Budapest University of Technology and Economics	EPS TriTel P/L LMP P/L
Danish Technical University	uCAM P/L
Politecnico di Milano	AIV TCS
Supaero	Star Tracker P/L
Instituto Superior Tecnico	ACS S/S Reaction Wheel P/L
Villafranca (Spain)	Ground Station North
Massey University (New Zealand)	Ground Station South
Politehnica University from Bucharest	Structures
University of Zaragoza	Mission Analysis Flight Dynamic System
University of Warsaw	Configuration OBDH Operations MCC
University of Wroclaw	TM/TC
Università del Sannio	SYS EGSE (TCC)
University of Glasgow	Harness Mission Exploitation
AMSAT	AMSAT P/L, transponder

Table 3.1: Involved University Teams and Organizations

3.1.2 Mission Requirements

Table 3.2 resumes the initial requirements defined as guidelines for the development of the ESEO mission [16].

Spacecraft Requirements		
Dimensions		max. $1000 \times 1000 \times 1000 \text{ mm}^3$
Mass		$\leq 100 \text{ kg}$
Mission lifetime		6 months (extendable)
Power	Average	100 W
	Peak	180 W

Table 3.2: ESEO Mission - Spacecraft requirements

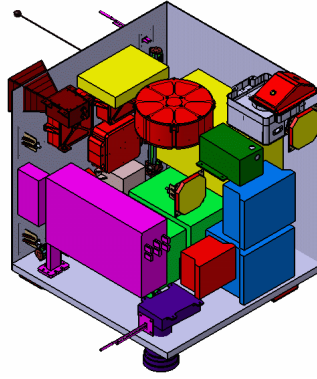


Figure 3.1: ESEO Preliminary concept

3.2 ESEO Mission

3.2.1 ESEO Architecture

The ESEO mission can be divided in three main parts:

- Space Segment
- Ground Segment
- Launch Segment

The Launch Segment is not in charge of CGS. ESA will provide the launch opportunity. Table 3.3 and 3.4 present the two other segments and their subparts developed by the university teams with CGS support.

Space Segment		
ESEO Satellite	ESEO Platform	OBDH EPS TM/TC AOCS Harness TCS Structure
	Payload	uCAM TriTel-S LMP Star Tracker Reaction Wheel Amsat P/L

Table 3.3: ESEO - Space Segment

Ground Segment		
Mission Operation	Mission Control Center	Main Control Center Mission Planning System Flight Dynamic System Network Interface System
	Ground Stations	North Station South Station
	AMSAT Ground Support Center	
	User Segment	
Ground Support Equipment	MGSE	
	EGSE	
	OGSE	

Table 3.4: ESEO - Ground Segment

Figure 3.2 shows the logical interconnection of the Mission Operation subpart elements.

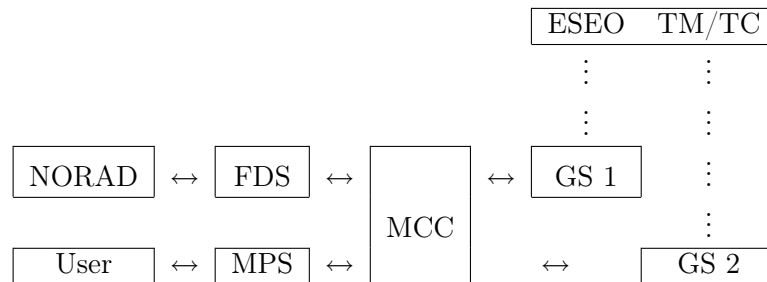


Figure 3.2: Logical Diagram - Mission Control Center and Ground Stations

3.2.2 Mission Objectives

The primary objective of the ESEO project is to provide students with valuable and challenging hands-on space project experience across all disciplines and throughout the full project life cycle in order to fully prepare a well qualified space workforce for the future. Table XXX presents ESEO mission objectives.

Mission Objectives	
1	ESEO will take pictures of the Earth and/or other celestial bodies from Earth orbit for educational outreach purposes.
2	ESEO will provide measurements of the radiation environment in low Earth orbit and its effects on satellite components.
3	ESEO will test technologies for future education satellite missions: for example ESMO, the educational lunar observer.

Table 3.5: Mission Objectives

The first one will be achieved by the use of a micro camera (uCAM) that, operating in the visible part of the spectrum, will acquire pictures of the Earth in a 8 bit gray-scale. The acquired images will be used for educational outreach purposes. At the current stage of the design process, some possibilities of improving the performances of the instruments are under evaluation, in particular the use of a RGB detector to have pictures of better quality.

To fulfill the second objective two instruments for measuring the characteristics of the space environment will be operated:

1. The plasma diagnostic probe *Langmuir Probe*. It will measure:
 - a) electron density
 - b) electron temperature
2. The dosimeter instrument *Tritel-S*. It will measure:
 - a) LET spectra
 - b) absorbed dose
 - c) dose equivalent
 - d) integral proton flux
 - e) electron flux

The realization of the third objective will consist in the flight testing of two ACS equipments designed by student teams:

1. A star tracker
2. A reaction wheel

Functional and performance tests will be performed during the satellite operative phase and the results examined on ground by the design team. The objective is to gain a full space qualification of the items to allow their use on future space missions. In particular their implementation on further educational missions is desirable, as for example ESMO.

3.2.3 Mission Constraints

The ESEO mission shall be performed with a space segment with a maximum mass of 120 kg and the occupied volume shall not exceed $800 \times 800 \times 1000\text{ mm}^3$.

Concerning the launch, the main constraints are:

1. ESEO Mission shall begin from a launch that shall inject the satellite into a Sun Synchronous LEO;
2. Mission objectives shall be acquired independently of the launch window;
3. The ESEO Mission shall be designed to be compatible with secondary/auxiliary/shared launch opportunities;
4. The ESEO Mission shall be designed to be compatible with all the following launchers:
 - a) Vega (baseline launcher)
 - b) Eurockot
 - c) Dnepr
 - d) PSLV
 - e) Atlas



Figure 3.3: Vega launcher

3.3 ESEO to date

3.3.1 Mission Orbit

The selected orbit for the ESEO mission is a circular Sun-Synchronous Orbit (SSO), with 10:30 LTAN and an altitude that should be around 520 km to satisfy the Code of Conduct for Space Debris Mitigation.

Since the exact orbital altitude is not yet defined, as the satellite will be embarked as secondary payload, the nominal orbital inclination is not available but it will be around 97° . The initial RAAN and true anomaly cannot be chosen as well, since both the launch date and the launcher are not defined yet. It must be said that initial inclination, RAAN and true anomaly do not play a major role on the mission analysis. The SSO inclination varies very little with the altitude, the initial RAAN just determines the launch window in order to be compatible with the 10:30 LTAN requirement, whereas the initial true anomaly just determines if the spacecraft injection occurs in sunlight or in eclipse.

3.3.2 Mission Phases

For ESEO, starting from the launch event, the following in orbit mission phases are foreseen:

1. Launch and early operations phase (LEOP)
2. Operational phase
3. Extended phase
4. Post mission phase
5. Satellite disposal

During *LEOP* a first functionality check on all subsystems is done. At the same time the sun-pointing attitude must be acquired and in this status all payloads will be sequentially switched on and tested to verify their performance.

The *Operational phase* follows which is the core of the in-orbit phases and will last at minimum 6 months. All payloads are activated in cycles of 28 orbits and the data produced is processed and transmitted to Earth to allow further evaluation by university teams. At the end of the six months the satellite is checked to see if additional measurements can be done and if possible, in accordance with the costumer, the Operational phase will continue in the *Extended phase* for a maximum of two more years.

After the partial or full completion of the Extended phase the *Post mission phase* starts. The ESEO spacecraft acts here as a transponder for AMSAT Radio-amateur community. In this phase only the TMTC and EPS S/S are active to provide the necessary requirements to fulfill the phase objectives. The transponder should be active at least for 3 years.

At the end of operational life the satellite is switched off to let itself naturally decay into Earth's atmosphere since the spacecraft has no propulsion S/S for a commanded deorbiting operation. When the *Satellite disposal* starts it must not exceed 25 years in accordance with the Code of Conduct for Space Debris Mitigation [12].

3.3.3 Payloads

The P/Ls operating on board ESEO, as already listed in paragraph XXX, are described in the sections below [11].

3.3.3.1 uCAM

The uCAM instrument (figure 3.4) will provide pictures of the Earth and maybe other celestial bodies to support educational outreach and public relation purposes for the ESEO mission. During the operational phase images will be acquired in an 8-bit grayscale but the possibility of having 8-bit RGB color images is under evaluation. The uCAM instrument provides a field of view which corresponds to an area of approximately 170000 km^2 or roughly a 468 km by 364 km ground swath with the satellite orbiting at 520 km of altitude. The uCAM instrument will be capable of producing images of recognizable ground features (e.g. the entire nation of Denmark), as well as monitor climatic changes: observe cloud formation, deforestation, ice movements in polar regions or large oil spills in the sea. Furthermore, the high sensitivity of the CCD sensor allows night time photography to reveal illumination of large urban areas.

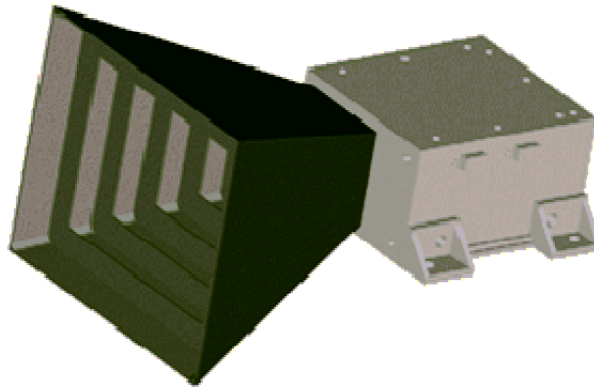


Figure 3.4: The uCAM instrument

The uCAM is based on a miniature camera unit, developed in Denmark since 2004 principally for pico-class satellites ($< 1 \text{ kg}$). It is the smallest space qualified CCD imaging system in the world. The ESEO project will provide continuity in the knowledge of the object after extensive tests onboard stratospheric balloons. With this mission opportunity, the instrument can provide the first

long duration in-flight demonstration and allow future utilization on board of almost every satellite class. This fact will be possible since the energy consumption is about $1 J$ for a single image frame, a quantity which wouldn't affect the platform of any satellite.

3.3.3.2 Tritel-S

A great problem during long-duration space flights, especially for manned missions, is the exposure to cosmic radiation. The radiation environment in space is a mixture of particles of different type and energy and varies considerably with time, altitude and additional orbital parameters. Concerning the origin of the cosmic radiation two main contributions can be distinguished:

- the so called galactic cosmic radiation (GCR), mostly consisting of energetic charged particles (protons, alpha particles, heavier ions and electrons in the energy range of $1 MeV-10^{14} MeV$) coming from outside the Solar System and
- the solar cosmic radiation composed of charged particles having a lower ($eV-GeV$) energy spectrum compared to galactic particles. The first component is often greater but due to solar flares this behaviour can change.

Zooming in near the Earth the radiation scenario appears even more complicated. Here the fluxes coming from the sun and from outer space meet the magnetic field of the Earth and the result are the Van Allen Belts. These are formed by trapped particles, electrons and protons, in the Earth's magnetic field. The intensity of the charged elements varies in space and time around the planet and for this reason, radiation measurements on board space vehicle are most important. Since an equivalent dose, which characterises the stochastic biological effects of the radiation, was defined in terms of a LET (linear energy transfer)-dependent quality factor, determining the LET spectrum and the quality factor of cosmic radiation is necessary.

The P/L is a specific adapted satellite version of the TriTel 3D silicon detector telescope, developed by the Hungarian Academy of Science KFKI together with the Atomic Energy Research Institute AEKI. The student team is so supported by experts of the AEKI who have decades of experience in high reliable nuclear and space instruments.

The measurements of the TriTel-S will be the LET spectra of the cosmic radiation and the dose equivalent. This data can be compared with other results of the 3D silicon detector telescope, as for example with the measurements on board the ISS. For the future this element may be further developed to be able to fulfil interplanetary missions due to its compact design.

3.3.3.3 LMP

In the ionosphere and plasmasphere, the higher regions of the Earth's atmosphere, parts of floating molecules are ionized in state of plasma. The cause relies mainly in the electromagnetic radiation

coming from the Sun. The interaction between the magnetic field of the Earth and the charged particles causes them to fly along the lines of the magnetic field.

It is worth to investigate on the distribution and density of plasma since the scientific community doesn't know enough about them, neither about statistical features (occurrence in time and space, expansion), nor the physical processes which lead to their formation. The Langmuir Probe (LMP) is specifically designed to acquire data about the plasma environment in orbit, based on a simple and reliable design and the data analyses and processing is well established.

3.3.3.4 Amsat P/L

The AMSAT P/L has no particular scientific return since it is transponder used by the radio-amateur community principally during the Post mission phase. In addition the C-band beacon shall be used to test satellite attitude measurement techniques.

3.3.3.5 Star Tracker

The Star Tracker is a technological experiment on board of ESEO. It will be monitored during its operational cycles and qualification data will be produced in order to verify the proper functioning of the equipment during space flight. This element is of great importance since it will be used on the ESMO mission where it will be part of the AOCS system, and possibly on further ESA missions.

3.3.3.6 Reaction Wheel

The Reaction Wheel as well counts as an experiment. It plays a significant role for future designs of attitude control systems allowing precise maneuvering and attitude control without use of propellant. This element will be tested on ESEO and is intended to operate on future space missions on small satellites such as ESMO, the third ESA educational mission.

3.3.4 Space Segment Actual Budgets

3.3.4.1 Mass Budget

At the actual status of the project, heading towards PDR, the mass budget of the ESEO space segment is resumed in table 3.6 and in diagram 3.5 [13].

	With +20% margin	Without margin
ESEO Satellite	Mass [kg]	Mass [kg]
Platform	108.7	90.6
Payload	13.8	11.6
Total	122.5	102.2

Table 3.6: Mass Budget

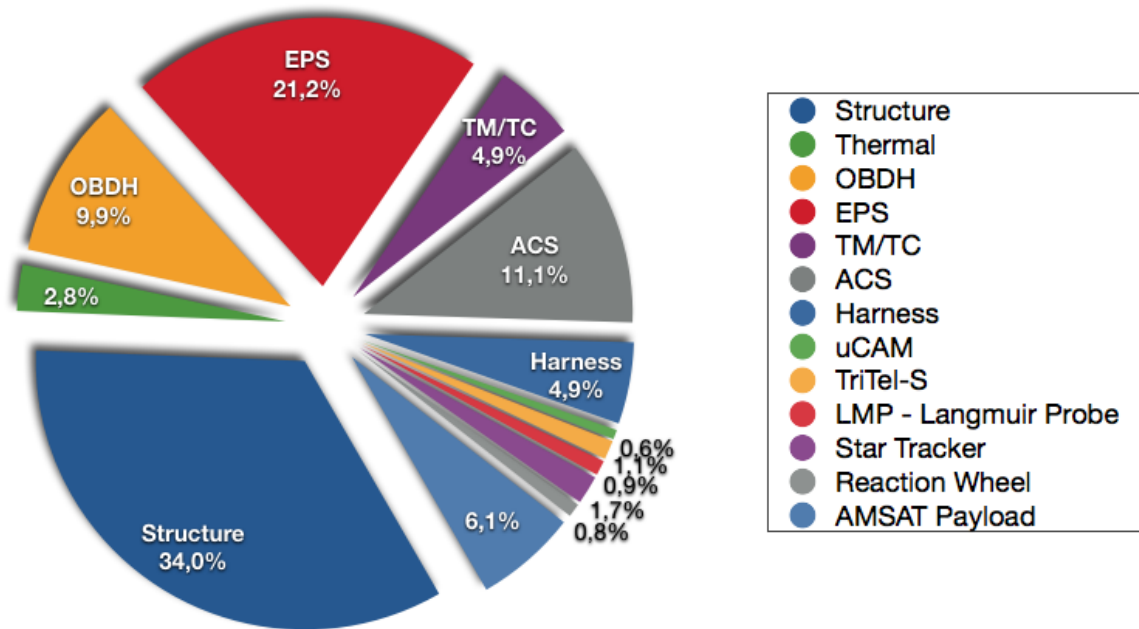


Figure 3.5: Mass Budget

3.3.4.2 Power Budget

The preliminary power budget at the end of phase B2 is presented in table 3.7 and figure 3.6 [13].

The budget is calculated over the dimensioning cycle, considering all modes operating during this cycle. The modes are then weighted upon their operating time to finally obtain the requested power. In table 3.7 the peak power is presented as well; it is a configuration that will never occur but it shows the requested power in a hypothetic fully operating scenario with all S/Ss and P/Ls switched on.

ESEO Satellite	Dimensioning cycle	Peak power
	Power [W]	Power [W]
Platform	103.6	158.1
Payload	3.0	80.9
Total	106.6	239.1

Table 3.7: Power Budget

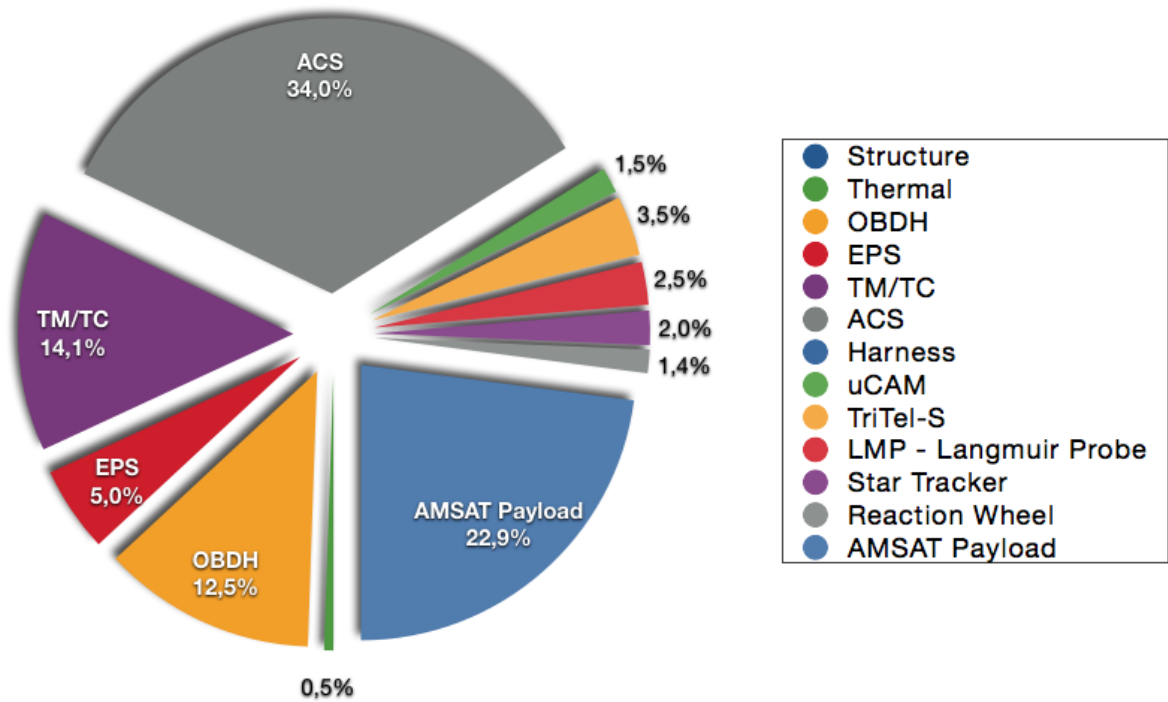


Figure 3.6: Power Budget over the dimensioning cycle

3.3.5 Satellite Configuration

At the present time the ESEO satellite has a cubical shape which mass is about 120 kg and its volume is $800 \times 800 \times 1000\text{ mm}^3$.

Figures 3.7 and 3.8 show the actual configuration of the spacecraft. In figure 3.7 the configuration reference axes are showed. The X-axis faces the sun to allow a constant illumination of the solar panel, the Y-axis points the north celestial pole and the Z-axis completes the right-handed frame.

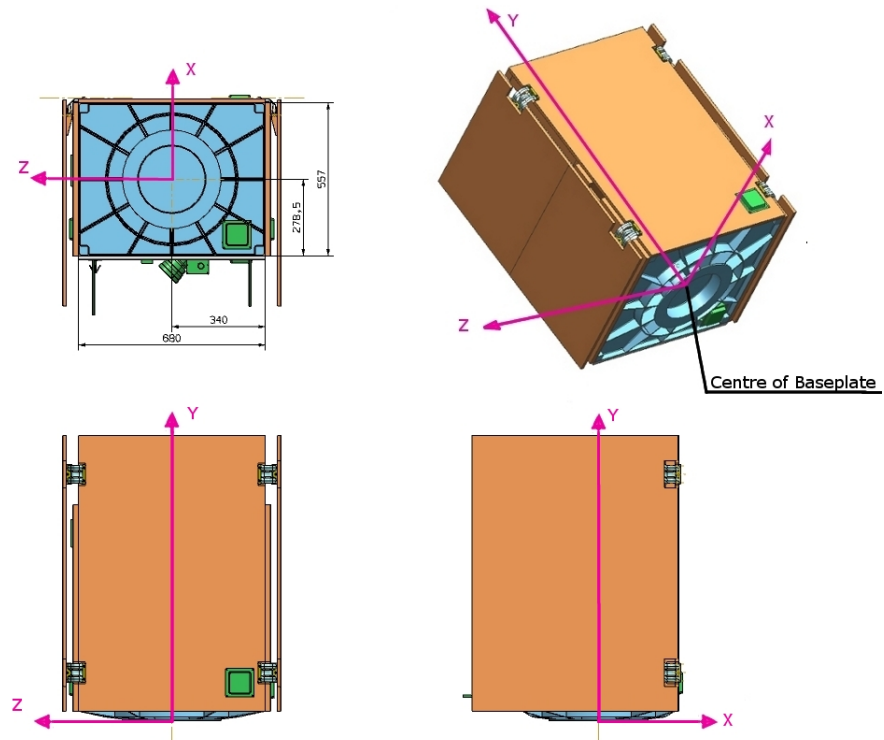


Figure 3.7: Actual configuration

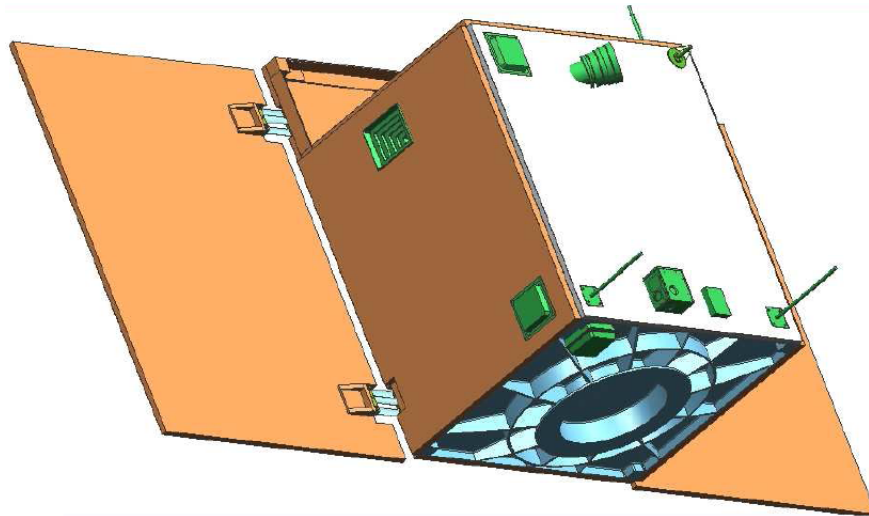


Figure 3.8: ESEO satellite with deployed solar panels

4 The ESEO DDP

4.1 Scope

The *Design and Development Plan* aims at describing the approach, process, methods and facilities chosen for a project execution. This chapter presents the DDP of the ESEO mission for all phases (table 4.1 and figure 4.1) during the whole project's life cycle [2,3].

Phase	Description
B2	Baseline consolidation & preliminary definition
C	Detailed definition
D	Production/qualification
E1	Launch campaign

Table 4.1: Project's phases

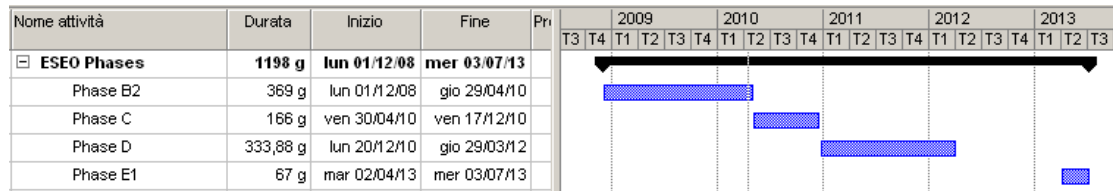


Figure 4.1: ESEO phases

4.2 Design and Development Logic

4.2.1 Design approach

For the design of the ESEO mission an easy solution and cost controlled approach are the baseline in all phases where design activities are present: these are phases B2, C, and part of phase D. The project teams shall always aim at fulfilling the mission requirements with the solution having the lowest overall cost. This approach will be followed at all levels of design, from equipment up to system level.

The selection of such a design solution will be achieved by means of a concurrent engineering approach. In the ESEO program this means developing a system design with the maximum interaction among different teams and among team members, even while focussing on individual work. The communication between people is granted through commonly spread information technologies thus allowing cooperation and confrontation between teams. In addition official reviews and deadlines are established to evaluate and validate the performed work.

In the D&D process of the ESEO mission and all of its elements every team operates autonomously. The prime contractor, CGS, follows the design and development through periodical documentation reviews and progress reports. The work is so done by the students, who propose specific solution options to satisfy the mission requirements but the final design is always submitted to the evaluation of CGS experts and also to ESA in further step for the design consolidation. In this way the concurrent engineering is really applied since a continuous exchange of information goes between the authority and the university teams, and in some cases between university teams only.

Not all items are developed completely by students, for some critical elements CGS gives a direct support so to guarantee adequate quality standards of the object within reasonable time and costs. In all other cases the university teams are confronted with the element's design complexities which allow students to grow professionally early during their studies in complete accordance with the ESA educational program philosophy.

Globally the concurrent engineering methodology will be applied by supporting all requested analyses and will ensure:

- optimization of the design in terms of budgets, performances and interfaces;
- immediate feasibility assessment about the implementation of each defined requirement with particular reference to the impact and consequences on the other subsystems or sub-assemblies;
- harmonization of the development process;
- easy information exchange among design teams;
- immediate reaction to critical issues or implementation problems;
- clear commitment from the key personnel in front of the rest of the team;
- clear definition of role and responsibilities.

The Design phase of ESEO is a crucial part of the project since it defines early in the life cycle the approaches and the procedures that lead to a mission's success. The customer shall give a clear list of mission's requirements, in particular concerning technical, design, schedule and quality aspects, so that possible conflicts between them can be identified soon and alternative solutions can be discussed and adopted. The defined requirements should then be allocated top-down from

system level down into equipment level and here translated into SW specifications. At all levels a requirement traceability system is implemented, a verification matrix is established and interface control documents (ICD) are defined. For critical items a risk mitigation strategy must be prepared and if possible simulations and analyses should start early in the process.

For a correct requirement verification approach specific ground support equipment (GSE) must be designed and produced in parallel to follow the development of an item through all project stages. Each university is responsible for the development of the element and for the equipment which verifies the element. On the contrary on SW level a responsibility separation philosophy is applied: who designs the SW is not who verifies the SW thus to avoid systematic errors, human errors and possibly requirement misunderstandings.

Generally, to verify requirements at all stages of the development, manufacturing and integration process, a bottom-up strategy from equipment up to system level is applied. An end-to-end verification step of the system requirements in the final system configuration will be applied as well.

A quality assurance plan will accompany the development of the whole project and key inspection points, milestones, are planned to verify and ensure quality of final products.

Furthermore for the space system design the following aspects must be considered as guideline in the system development as well:

- reduction of spacecraft mass, envelope dimensions, power consumption and data management resources as a mean for cost saving and efficiency;
- appropriate design margins philosophy is applied in order to match the proper design uncertainty in each phase of the design itself, to guarantee a correct margin apportioning on each subsystem and to avoid inefficient highly or poorly conservative design choices.

4.2.2 Project Development

The overall ESEO system development approach has as primary objective the finalization and consolidation of the aspects listed below, in agreement with the product assurance requirements and the ECSS standards:

- model philosophy definition at system and subsystem level;
- AIV approach definition;
- qualification and acceptance strategy definition.

***A large part of the development approach is related to the ESEO SW. Ground and flight SW shall be developed for system performances and functionalities achievement. Particular attention is put on flight SW design and development in order to guarantee the required space segment reliability and especially on board autonomy. For this reason the SW will be tested and developed since the very early phases on the HW environment (DM and EM) in order to resolve any interface and/or

compatibility criticality as soon as reasonably possible. Such approach has proved to be extremely effective to keep both schedule and working times within plans.

4.2.2.1 Adopted Model Philosophy

For an educational satellite project such as ESEO a protoflight approach with only one model is not a desirable approach, since it leaves no room for mistakes and/or redesigning of components and is therefore too risky. However, a tight budget and timeline do not allow the integration of several intermediate models before the flight model as for the prototype approach.

For this reasons a hybrid model philosophy is applied to the ESEO project in order to reduce cost and schedule while minimising risks. This approach has proven to be very efficient in other CGS developed missions.

The following three models will be considered at system level:

1. Electrical Engineering Model (EEM)
2. Structural Thermal Model (STM)
3. Protoflight Model (PFM)

On the other hand, at payload/unit-level there shall be these models:

1. Development Model (DM)
2. Engineering Model (EM)
3. Protoflight Model (PFM)

Of these models the DM is not produced for all S/S and P/L. It will be realized principally for critical designed items and in that cases they will not be delivered neither to CGS nor to ESA facilities for verification and testing.

Each element of the ESEO project will follow the hybrid model philosophy to harmonize both payload and platform.

4.2.2.2 Verification Process

To speed up the preliminary project phase, the selection of the AIV approach is carried out in parallel with the definition of the AIV elements listed below. The idea is the “work in the loop” principle to fasten events. Here the main AIV aspects to define:

- AIV and test facilities;
- the GSE;
- the AIV plan.

The first step of the verification process is verification planning. It starts at all levels as soon as the requirements are identified, directly after SRR. The plan defines all methods of verification, and all levels and stages at which the verification has to be performed in relation to the system or subsystem requirements. If the verification method is by test, the model on which the test has to be performed must be defined. The flow that goes from the requirement definition to the verification methodology leads to the establishment of a verification matrices, which includes all project levels. For ESEO the verification shall take place at three levels:

- unit/payload level;
- S/S level;
- system level.

Each University carries out a first verification step on their equipments before delivering the items to the system prime at the central facility for global AIV activities. The system prime is responsible for achieving the qualification and acceptance of the system.

Generally the preferred verification method, to verify that the design satisfies the requirements imposed by the mission, is test. In some cases more than one test can be executed at the same time. Analyses as well can be done to verify the requirements satisfaction. To verify in orbit operations instead, indirect verification methods through simulated mission scenarios are adopted. In the verification process all tests and analyses required by the launch authority are executed as well.

The detailed description of the verification program and all related activities is stated in the AIV Plan.

4.2.2.3 Qualification and Acceptance

The ESEO System verification strategy follows the protoflight philosophy. It will be executed at system and subsystem level.

Consequence of this approach is the combination of qualification and acceptance stages. The fact is underlined in particular during environmental and mechanical tests. Before proceeding with the test campaign on the PFM, tests are performed on the STM with qualification levels and durations which implies the worst mechanical case and thermal environment plus an adequate qualification factor to consider proper safety margins.

In a successive phase, the PFM is tested for the acceptance campaign using qualification levels but shorter acceptance durations. The objective is to reduce to the minimum the invasive actions during tests, in order to avoid excessive stresses on the PFM. Test repetitions must be avoided and the actions flow must be optimized.

The following table summarizes the different verification methods used in the verification stages on the various system levels for all S/Ss.

Segment	Element	Subsystem	Qualification	Acceptance	Pre-launch	In-orbit
SPACE	Satellite	ACS OBDH Harness Structure Thermal EPS TM/TC Payloads	T, A, R, I	T, A, R, I	T (reduced), I	T
GROUND	Mission Operation	MCC Ground Stations User Segment		T, A, R, I	T,I	T

T-test, A-analysis, R-review of design, I-inspection

Table 4.2: Verification matrix at system level

4.3 Schedule and Reviews

4.3.1 Milestones

Table 4.3 presents the ESEO program system milestones.

Milestones		
1	Mission Definition Review	MDR
2	System Requirement Review	SRR
3	Preliminary Design Review	PDR
4	Critical Design Review	CDR
5	EEM & STM Delivery	
6	Qualification review	QR
7	PFM Delivery	
8	Final Acceptance Review	FAR
9	Launch Readiness Review	LRR

Table 4.3: ESEO Milestones

4.3.2 Planning

In the following diagram all the ESEO mission phases with the correspondent milestones are presented.

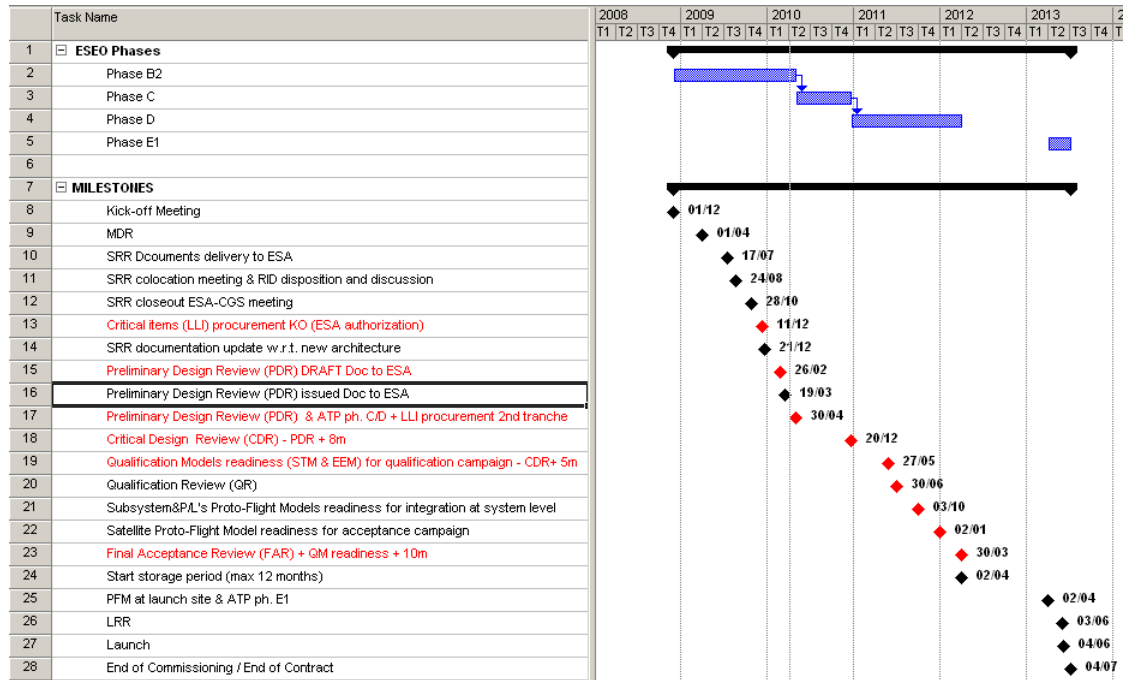


Figure 4.2: ESEO Mission schedule

4.4 Design and development activities

4.4.1 Space Segment

4.4.1.1 Satellite Design and Development

Design activities are the major task of the B phase. The design will be then refined and finally frozen by the end of phase C for all elements. At the end of this process, the procurement of the materials, parts and components for the design verification models will start. The successful completion of qualification and acceptance testing will confirm the design readiness for the successive launch campaign.

4.4.1.1.1 Procurement - LLI The narrow schedule, for meeting the launch event in 2012, leads to the procurement of long lead item (LLI) before the beginning of the phase C/D but after the design consolidation of the platform. The early procurement phase of material, parts and components will be focused on the production of the design validation and qualification models.

Design validation models material and parts procurement will focus on electronic and structural representative aspect. Thus, when possible, space qualified materials will not be used at this stage to reduce costs.

Quality control will verify consistency between supplied item and procurement specifications during incoming inspections.

4.4.1.1.2 Qualification Models For the qualification phase two main models at S/S and P/L level will be prepared: the engineering electrical model (EEM) and structural thermal model (STM). All elements must be delivered in phase D for the milestone *EEM & STM Delivery* (see figure 4.2, table 4.3).

EEM manufacturing will start as soon as the manufacturing electrical drawings are ready. The EM assembly and integration process will start after parts procurement and manufacturing. Platform EM tests are for the electrical/data/software qualification of the platform subsystems and payload interfaces, as well as to evaluate the functional performance of the selected design.

The EEM development shall take place during phase C, after PDR, continuing then in phase D with the delivery of the complete element to the test facility for the qualification campaign.

The STM manufacturing will start in parallel to the EEMs, as soon as the mechanical/structural drawings are ready. The STM includes the structure and parts of the thermal control subsystem representative of the flight model. Mass dummies representing the mass and the thermal properties of the platform subsystems and payloads, and distributed harness mass, will be incorporated in the structure for the tests. The STM assembly and integration process will start after parts procurement and manufacturing. Tests on the STM are for the mechanical/structural qualification.

As for the EEMs the item will be developed in phase C and part of phase D until delivery to the central test facility.

4.4.1.1.3 Acceptance Models After the delivery and verification of S/S and P/L PFMs the assembly and integration process of the ESEO space vehicle can start. The flight structure and all flight models of platform subsystems and payloads are integrated. The HW mounting process will be executed in suited facilities with required cleanliness class, in order to guarantee a high quality level of the product. All the activities will be headed and executed by skilled specialists and technicians. System-level verification of the PFM shall occur at qualification levels and acceptance durations for the acceptance campaign.

The PFM parts procurement will start after CDR at the beginning of phase D. Subsequently all PFM subsystem and payloads will be delivered to the central facility by the end of phase D to sustain the FAR (figure 4.2), proceeding then with the launch campaign.

4.4.1.2 Satellite integration, verification and test

4.4.1.2.1 Satellite integration The satellite integration starts as soon as both payloads and subsystems are fully integrated and tested themselves. All items must be therefore delivered prior to the milestone deadline, *PFM Delivery* (table 4.2), to the central facility where integration will be executed in adequate facilities with appropriate environmental conditions. The integration will be managed by skilled specialists.

At the integration site the following activities are performed in the presented sequence:

- mechanical and Electrical interfaces verification of all elements;
- preliminary integration test;
- platform + payload mechanical integration;
- platform + payload electrical integration;
- integration test and functional verification;
- final integration of the solar array support structure and of the solar array;
- final integration of the thermal blankets (Multi Layer Insulation - MLI);
- full functional test.

4.4.1.2.2 Satellite verification The verification implementation and documentation process starts in phase B. In this phase the verification will consist mainly of analyses, iterated with the design definition activity, aimed at demonstrating that the finally selected design concept is able to fulfil the mission requirements. This process ends with the PDR which freezes the selected solutions. The verification process continues in the successive phases until the commissioning. The list below reports the main areas where the design iteration in the loop is applied:

- mission analysis,
- thermal analysis,
- structural analysis,
- payload optical analysis,
- radiation analysis,
- ACS performance analysis,
- failure mode effects analysis,
- safety analysis.

4.4.1.2.3 Satellite test campaign At system level, once all S/Ss and P/Ls are integrated the following tests shall be performed on the space vehicle:

Measurement of the satellite mass properties

The centre of mass and the moments of inertia will be measured, not calculated.

Dimensional and alignment check

Physical properties of on board equipment are verified as well as the compliance to the alignment requirements.

Vibration / Acoustic / Shock test

The vibration and/or the acoustic test shall be performed to the levels and duration specified by the launch authority. The different launch providers have slightly different approaches to the spacecraft qualification for launch, in particular for what concerns the shock/release test. The test procedure shall be prepared in a successive phase considering the data provided by the selected launcher provider.

Thermal vacuum / Thermal balance

During the thermal vacuum test all the satellite subsystems will be verified for their operation in the expected operational temperature range. The thermal balance test will verify the performances of the thermal control subsystem with respect to the thermal mathematical model.

EMC (radiated emissions)

A satellite radio frequency (RF) radiation measurement is performed.

Integrated System Test (IST)

The full set of functional tests is performed and the results are compared to detect possible deviations caused by environmental solicitations.

Short Functional Test (SFT)

A reduced set of functional tests is repeated during the test campaign and the results are compared to detect possible deviations caused by the environmental solicitations.

System Validation Test (SVT)

The SVT will verify the system response in conditions that are as much as possible representative of the operating scenario.

Table 4.4 summarises the tests to be executed on the different satellite models during the project life cycle.

	Mass Properties	Dimensions/ Alignment check	Vibration/ Acoustic/ Shock test	Thermal vacuum & balance	EMC	IST	SFT	SVT
EEM						x	x	x
STM	x	x	x	x				
PFM	x	x	x	x	x	x	x	x

Table 4.4: Tests on system models

A detailed description of each test is included in the next chapter concerning the AIV Plan of the ESEO mission.

4.4.2 Ground Segment

The ESEO ground segment preparation process will follow the guidelines described in figure 4.2 [14].

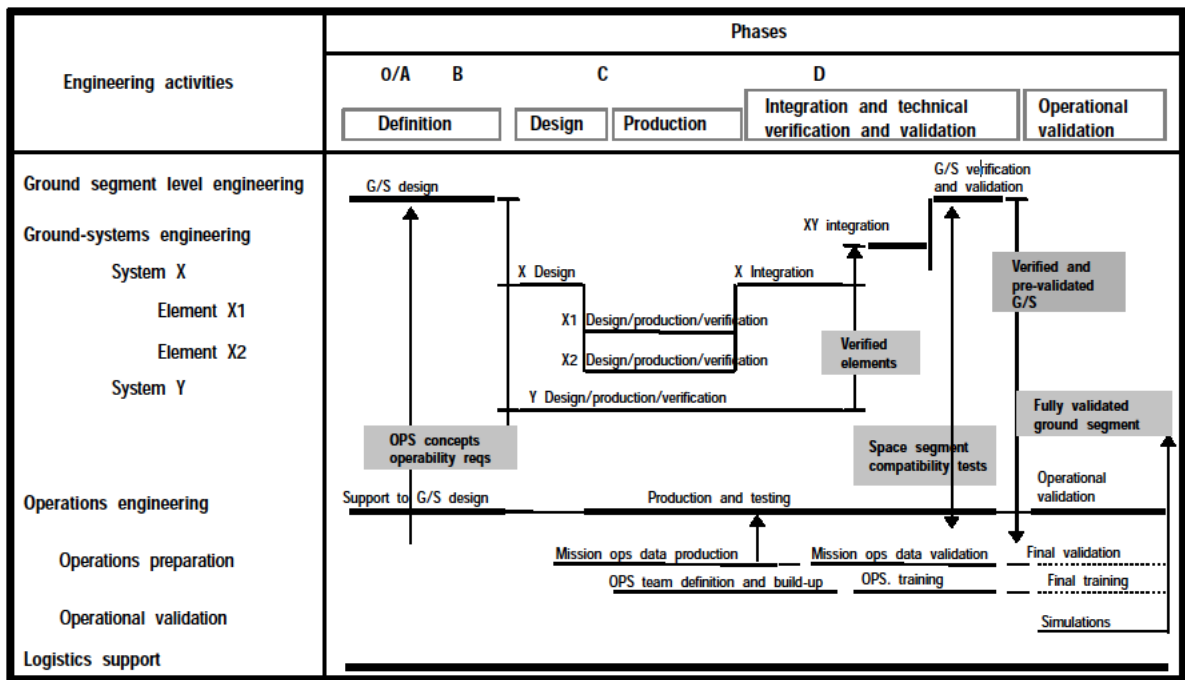


Figure 4.3: Ground Segment preparation process

The ground segment design activities shall cover three main lines:

- the ground segment level engineering, verification and validation;
- the ground segment system and subsystem design/production/verification;
- the logistics support and operation engineering.

Each of the three lines of activities is described in a short form in the next sections.

4.4.2.1 Engineering and AIV Activities

The System Engineering activities to be performed in the frame of the ESEO B2/C/D/E1 phases are aimed to specify the identified ground segment functions and build-up the technical specifications, down to subsystem level. The ground segment design starts with a definition of a coherent set of requirements allocated to ground segment and their interfaces, and proceed through a comprehensive set of analyses and verifications performed at all levels. The design will be documented for the different reviews through the definition of requirements and specifications, interfaces, development/verification/qualification plans, architecture and operational concept, configuration, performances and budget etc., for the complete ground segment and down to subsystem level.

The main System Engineering tasks foreseen in phases B2/C are the following:

- The requirements allocation/derivation is aimed to produce a set of requirements for the ground segment subsystems that are as complete, consistent and correct as possible. The functional specifications are frozen at SRR, together with the delivering of technical specification, in the frame of PDR milestone: it forms the baseline specifications of the ground segment to be used during the next phases.
- The performances are partitioned to the lower level subsystems.
- The ground segment architectural design and interface definition will be carried out according to relevant ECSS engineering standards, as tailored for ESEO.
- The ground segment AIV Plan identifies and specifies the approach and strategy of ESEO ground segment requirements verification, to be performed at different level of the product tree (i.e. segment, subsystems, etc.) and in the different phases during the development project life cycle (e.g. design, development, etc.), applying a coherent bottom-up incremental approach and using a suitable combination of different verification methods. The coherence of the approach will be supported by the ESEO ground segment requirements analysis.

Activities foreseen during D/E1 phases are:

- Following the approach defined and described in the AIV plan, detailed integration and verification test procedures are produced, including the specification of test cases at segment and S/S levels. Analysis and verification of consistency of AIV activities at system and lower levels are executed as well.
- In accordance with the ground segment AIV, all subsystems are integrated and the ground control segment is verified. Related test reports are produced.
- Support to upper level validation is provided.

4.4.2.2 G/S Design and Development

The activities concerning design and development of the ground segment and all of its parts will be carried out, from phase B to phase E1, according to the logic described in the paragraphs below.

4.4.2.2.1 Phase B The requirements definition represents the core activity to be executed in phase B. This activity starts at the SRR and ends at the completion of the PDR. Purpose of this phase is to achieve a precise definition of the ground segment S/Ss baseline in order to confirm its feasibility, to prepare the choice of supplier(s) and support the decision to start its implementation.

During this phase the segment is decomposed into its main elements and the ground system requirements will be analyzed to indentify detailed subsystem requirements. At the end of phase B, the requirements and external constraints for the subsystems shall be frozen. In parallel with the S/S requirement definition, the consolidation of the high level architecture must be analyzed and freed.

The completion of these activities provides a preliminary definition of the ground segment architecture which will be used as input for the subsequent project phase.

4.4.2.2.2 Phase C Phase C activities for the ground segment start after the completion of the PDR and end at the CDR. In order to proceed with this phase all outputs shall be updated after PDR and a first set of documentation shall be ready. Phase C is mainly devoted to the detailed design of the ground segment: the design is refined and implementation starts.

The C phase will consolidate the baseline definition: design definition files and requirements documents, containing functional and operational requirements, in final version must be prepared. The architectural design specifications shall be published in the final version, as well as subsystem interface control documents, S/S AIV plans and S/S design justification files. Eventually a risk evaluation plan and possible safety measures must be produced.

4.4.2.2.3 Phase D Phase D starts at CDR and ends at FAR milestone. To fulfil phase D, all updates issued at CDR shall be available. In particular the space segment user manual shall be available. To allow validation and verification, representative telemetry data samples shall be prepared and ready for use as well. The overall purpose of phase D is the system implementation, which includes production, engineering and procurement of all subsystems elements, both HW and SW. The SW is fully developed, that means coded, tested and integrated so that simulations can be executed. The simulation tools are for test, calibration, validation and training activities.

Furthermore in phase D the planning and execution of on-ground instrument calibration, planning of standard processors calibration and standard products validation will be executed. Tools for simulations and test are prepared, verificated and validated. All S/S will be integrated to a fully operational ground segment that is ready to support in-orbit operations and exploitation of the space segment.

At the end of phase D the validated MCC as part of the ground segment must be ready as well. All subsystem AIV activities must be finished with the related test results and all technical verification, calibration and validation reports must be completed.

4.4.2.2.4 Phase E1 The input to phase E1 shall be fully qualified and operating subsystems.

In this phase the following tasks will be executed by the ground segment:

- support LEOP;
- follow and support the mission orbit acquisition, test and commissioning;
- handling of possible anomalies.

4.4.2.3 Operation Preparation

This paragraph describes the activities performed during the ground segment realisation phase and before LEOP, as preparation of the in orbit operations. All necessary activities to the correct organization and the execution of the operations are included in the operation preparation phase. These activities begin before the launch of the satellite and continue through the successive phases (LEOP, commissioning, etc.). Starting from the system level definition, the following activities will be carried out at ground segment level:

- study and revision of the operative documentation provided by the spacecraft manufacturer;
- support to the Mission Operation Segment development and to AIV activities;
- preparation of the System Validation Test (SVT) / System Operation Validation Test (SOVT) plan / procedures and report;
- preparation of the Flight Operational Procedures (FOP);
- preparation of the Mission Operation Plan;
- preparation of the Sequence of Events document related to the Launch phase and first spacecraft acquisition;
- preparation of the commissioning plan and procedures;
- ground segment acceptance test plan and report;
- SVT/SOVT execution;
- pre-launch simulation sessions execution.

The activity of familiarisation with the satellite has the objective of the acquaintances of the satellite, both of platform and payload. The aim is to concur in the development activity of writing the operational procedures and the execution, during the operational phase, of the following tasks: monitoring and control of the satellite, evaluation of performances, diagnostic analyses of eventual anomalies. The familiarisation process happens through the study of the technical documentation of the satellite (specifications, operational requirements, satellite user manual, etc.). For its achievement, CGS will be responsible to supply the documentation of the satellite in agreement to the planned schedule and to guarantee the opportune technical interfaces between the design teams of ground and space segments.

The activity of support to the Mission Control Centre development consists in the review of the documentation produced for the Control Centre and in the contribution to the planning and execution of the acceptance tests.

Concerning the activity of satellite database population and customization, it will consist in the completion of the database imported from the Mission Control Centre. As already experimented for other missions, this approach will allow a remarkable save of time in the population of the database with telemetries and telecommands.

The aforesaid completion will consist in the definition/configuration of alphanumeric displays, graphic displays and mimics, in the definition of derived parameters and related derivation routines and in the definition of validity parameters needed for telecommand verification purposes.

The SVT/SOVT Plan preparation for the execution of the related tests, consists in the definition of a document. This document illustrates the system configuration to prepare for the test execution, the timeline and sequence with which tests will be executed for every on board S/S and the forms and standards to be used for the test reports. The plan must be agreed with the System Prime. The SVT/SOVT Test procedures will involve all subsystems and payloads. In preparation to the execution of the first SVT/SOVT session, the recorded telemetry necessary to the Control Centre debugging activity will be supplied.

The Flight Operational Procedures writing activity consists in understanding the operating procedures of the satellite. They are inserted in the Satellite User Manual and their customization is allowed in a modality which must satisfy both Control Centre and satellite requirements.

The Sequence of Events shall describe the operational activities at high level to be performed from a few hours before launch, in order to execute the foreseen verifications which leads to the “go no-go” event, to the launch. Furthermore the activities after the launch relative to the first acquisitions, verifications on the state of health of the satellite and reactions to contingency situations are described. OK

The next step, as for the SVT/SOVT Test sessions, is the preparation of a plan of activities for the commissioning phase of the platform and the payload. This document describes all the in orbit verification activities to be performed referenced to the applicable procedures. The ESEO Operation Plan includes management methodology of the activities, training of the operation team, description of the roles and the responsibilities, description of the mission operational scenarios.

4.4.3 Launch Activities

When all satellite integration steps are accomplished, an accurate procedure for packing and shipping will be followed to guarantee safety, cleanliness and the successful sequence of operation that will allow the transportation of the satellite from the integration facility to the launch site. For the completion of the procedure, the following elements shall be available at the integration facility and at the launch site:

- dedicated satellite transport container;

- dedicated MGSE;
- integration stand at the integration site;
- verification stand at the launch site (this could be the integration stand with little changes);
- dedicated hoisting devices, as necessary;
- standard equipment to allow the introduction of the satellite in the transport container, and the movement of the container itself;
- clean inert gas (Nitrogen) supply to fill the transport container.

The ESEO launch service is provided by ESA. The ESEO team will be nevertheless in charge of all engineering activities related with the launch preparation and launch campaign. The launcher I/F specification document will be prepared for PDR. The launcher selection will be performed within the platform CDR.

In order to guarantee the technical and programmatic interfaces, contacts with the launch service provider will be maintained. The universities will always be involved in the information and decision flow. The following activities are foreseen:

- launch mechanical and electrical I/F definition and input generation for satellite refinement;
- launch service provider interaction for technical verification and mathematical/dummy satellite models exchange;
- verification of the compliance of the spacecraft and operations to the safety regulation of the launch site;
- safety reviews preparation and conduction;
- preparation and performance of environmental tests according to the requirement of the launch provider;
- preparation and maintenance of the documentation required by the launch authority;
- configuration refinements, if necessary;
- preparation and review with the launch provider of the procedures to be performed at launch site.

A typical timeline for the launch preparation activity is 24 months from the launch agreement to the launch date. In this timeframe, two main activities are foreseen:

- the preliminary definition phase going from 24 months to 15 months prior to the launch event;
- the final definition phase from 9 to 3 months before launch.

In the first phase, all the requirements from both parties are analyzed and finally frozen, and a first issue of the interface control document is issued. A coupled analysis with the preliminary model of the satellite and the launcher is performed.

During the time between the two high intensity phases, the interface control document must be frozen, the satellite structural model is subject to test to verify the compliance with the launcher requirements, the documentation required by the launch provider is prepared, and the launch site procedures are preliminarily agreed.

In the second high intensive phase, the respect to requirements is verified on the basis of:

- environmental tests at satellite level;
- coupled analysis between launcher and the final satellite model;
- safety review results;
- mechanical/electrical interface check.

In this phase the launch site procedures are finalized and agreed between the parties. This timeline is applicable with some minor difference to all launch providers.

4.4.4 Launch Campaign

The satellite is delivered at the integration facility of the launch site. Here a careful unpacking procedure allows the ESEO satellite in clean room by means of its MGSE. Through the available EGSE the satellite is checked before integration on the launch adapter. After permission through an apposite review, the flight readiness review (FRR), both satellite and its adapter can be integrated on the rocket.

At this point, the final verification is performed and the fairing can be closed. Power is then connected to the satellite through an appropriate cable to keep the battery in the specified charge condition until the launch event.

At the scheduled time, the rocket is transferred to the launch pad. The LRR gives the final authorization to launch after the verification that the complete system - satellite, launcher, MCC and ground stations - is fully operative. The launch count down leads to take off.

4.4.5 Commissioning

After launch into the selected SSO the ESEO satellite will at first deploy its solar panels and point them towards the sun, acquiring its nominal attitude. Student teams will at this point follow the other commissioning operations of S/Ss and P/Ls during LEOP.

5 The ESEO AIV Plan

This chapter contains a detailed description of the AIV activities for the ESEO project, both for the space and the ground segment. All the content refers to a preliminary version of the planned activities, since PDR will take place by the end of the first part of 2010 [2,3].

5.1 AIV Concepts and Approach

5.1.1 Model Philosophy

In order to minimize the cost and the system development schedule, the adopted model philosophy for the ESEO mission is the hybrid approach, as already described in paragraph 4.2.2.1.

5.1.2 Test Philosophy

The ESEO test philosophy is in accordance with the testing philosophy described in paragraph 2.2.2. The main guidelines are listed below.

- test programmes are an essential part of the overall verification to ensure that the product achieves all the design, performance and quality requirements;
- test planning, requirements and criteria shall be derived from the design requirements;
- all product specifications shall indicate their intended verification method, see table 2.3;
- starting from the verification matrix, a dedicated test matrix shall be prepared defining the detailed types of tests to execute on each item;
- based on the test requirements, a test plan shall be established as part of the overall verification plan;
- the test plan shall:
 1. describe and sequence all the tests;
 2. state the objectives and the scope of the tests;
 3. specify the test facilities;
 4. govern the execution of all tests.
- the determination of test sequences should be based on two main considerations:

1. preserve the order in which environments are encountered during the operational life;
 2. detect potential failures and defects as early in the test sequence as possible;
- the overall test programme shall encompass different stages (see table 2.1) at different project levels and in different phases;

5.1.3 Test Conditions

Test	Levels		Duration	
	Equipment	Space element	Equipment	Space element
Shock	+6 dB ^a	N/A	3 shocks in both directions of 3 axes	3 activations of explosive firing
Acoustic	+4 dB ^a	+3 dB	2 min ^b	2 min ^b
Vibration	Random/Sine: +4 dB	Random/Sine: +3 dB	Random: 2,5 min per axis ^b Sine: 2 octave/min 1 sweep up and down (5 Hz-100 Hz)	Random: 2 min per axis ^b Sine: 2 octave/min (5 Hz-100 Hz) (notching, if necessary)
Thermal cycling	10 °C extension of maximum and minimum predicted temperatures ^a	10 °C extension of maximum and minimum predicted temperatures ^c	8 cycles	8 cycles
Thermal vacuum	10 °C extension of maximum and minimum predicted temperatures ^a	10 °C extension of maximum and minimum predicted temperatures ^c	8 cycles if combined with thermal cycling, 1 cycle if thermal cycling is performed	8 cycles if combined with thermal cycling, 1 cycle if thermal cycling is performed
EMC	+6 dB EMC safety margin		depending on operating modes	
Static/acceleration	1,25	1,25	100 s + 50 s per mission	Sufficient to record test data
Pressure	1,5 (proof), 2 (burst)	1,5	5 min (3 cycles for valves) only for proof	5 min (3 cycles)
Life	N/A (margins only for accelerated tests)		4 times operating life	
^a If the equipment qualification is carried out for multi-project utilization standard spectra or temperature limits can be used. ^b Duration is dependent on the number of missions. ^c A suitable distribution of the flight delta temperature for equipment is used, i.e. temperature limit is reached as soon as one unit in a selected area is at the hot and cold temperature reached during the unit qualification thermal testing.				

Table 5.1: Qualification test levels and durations

Test	Levels		Duration	
	Equipment	Space element	Equipment	Space element
Shock	Maximum expected shock spectrum	N/A	1 shock in both directions of 3 axes + dwell and burst tests	1 activation of explosive firing
Acoustic	Envelope of maximum expected acoustic spectrum		2 min	1 min
Vibration	Random: Envelope of maximum and minimum expected spectrum ^a	Random: Envelope of maximum and minimum expected spectrum ^a	Random: 2 min per axis	Random: 1 min per axis
Thermal cycling	5 °C extension of maximum and minimum predicted temperatures ^b	Flight temperature ^c	4 cycles	4 cycles
Thermal vacuum	5 °C extension of maximum and minimum predicted temperatures ^b	Flight temperature ^c	4 cycles if combined with thermal cycling, 1 cycle if thermal cycling is performed	4 cycles if combined with thermal cycling, 1 cycle if thermal cycling is performed
Pressure	1,5	1	5 min (only one cycle)	Sufficient to establish leakage
^a For random acceptance test spectrum see 4.8.1.3 d. For the equipment, the minimum spectrum is the acceptance vibration test (AVT) spectrum having no relation with the expected mission and derived from experience on several projects. ^b If the equipment acceptance is carried out for multi-project utilization standard spectra or temperature limits can be used. ^c A suitable distribution of the flight delta temperature for equipment is used, i.e. temperature limit is reached as soon as one unit in a selected area is at the hot and cold temperature reached during the unit acceptance thermal testing.				

Table 5.2: Acceptance test levels and durations

Table 5.1 shows test conditions applied for the qualification of the STM. In the case of PFM these tests are executed considering qualification levels and acceptance durations (table 5.2).

5.1.4 Verification Strategy

5.1.4.1 Verification Methods

The verification process shall be accomplished by means of one or more of the test methods already described in chapter 2. The choice of one or more of these methods is based upon design analyses, design maturity (technology readiness level - TRL), complexity of the item, criticality category and associated cost. Analysis and Testing are the better suited methods to verify performances but are more expensive as well.

5.1.4.2 Verification Levels

The verification activities will be performed at different complexity levels. The verification programme analyses single items and then proceeds to consider each subsystem. The next step is focussed on the elements of the system. The verification ends with the evaluation of the overall system.

The requirement verifications will be executed at the following levels:

- Equipment unit/payload: single units or electronic boxes;
- S/S level;
- System: full integrated space segment and ground segment.

5.1.5 Verification Stages

The verification process at system level is divided in the following steps:

- Qualification stage
- Acceptance stage
- Pre-launch stage
- In-orbit (including commissioning) stage

In the qualification stage the verification objective shall be to demonstrate that the design meets all the applicable requirements and includes proper margins. During the qualification stage the system, both space and ground segment, shall be produced and ready to be tested. The qualification stage at system level ends with the milestone QR.

In the acceptance stage the verification objective shall be to demonstrate the compliance with the applicable requirements and that the item is free of workmanship defects and integration errors and is ready for subsequent operational use. The acceptance stage will determine if the system is ready to be launched. In the mission schedule this stage ends with the milestone FAR. After the acceptance review in fact the spacecraft can be shipped to the launcher facility and starts the launch campaign phase.

The verification objective of the pre-launch stage shall be to verify that the space segment, the spacecraft, and the ground segment, the ground stations and all the launcher supporting system, are properly operating and ready for launch. The LRR gives the final authorization to proceed with the launch event.

The in-orbit stage verification objective shall be to supplement ground testing by providing operating conditions which cannot be fully or cost effectively duplicated or simulated on the ground. During this phase the functionalities, the performances and the operations of the overall system will be tested to verify the compliance with the mission requirements. Besides the verification tests the calibration operation shall be performed. After the successful completion of these verifications the mission can enter its operational phase.

5.1.6 Organization and Management of AIV Activities

The AIV plan describes the responsibility and management tools applicable to the AIT process. Furthermore it describes the responsibilities within the project team, the relation to product assurance (PA), quality control (QC) and configuration control (tasks with respect to AIV, including e.g. anomaly handling, change control, safety, and cleanliness) as well as the responsibility shared with external partners. The planned reviews and the identified responsibilities are also included. These paragraphs describe the overall organization and management techniques for performing the ESEO Satellite assembly, integration and verification activities presented in the plan. The main tasks to be performed are:

- Monitoring of Subsystem activities for verification purposes;
- AIV Plan preparation and control;
- integration/test procedures preparation;
- integration/test activity execution;
- integration documentation preparation;
- test and verification reports preparation;
- control of analysis reports for verification purposes.

5.1.6.1 Organization

The overall verification process will be conducted by a dedicated AIV Team which is responsible of the following tasks:

- Verification management;
- interface with the external teams involved in the verification activities;
- AIV Plan preparation;
- preparation of detailed integration & test planning and schedules;
- preparation of integration and test procedures;
- design, preparation and utilization of integration and test tools;
- procurement and maintenance of AIV tools;
- interface with test facilities;
- execution of integration and test activities;
- chairing of test readiness review (TRR) and post test review (PTR)

- monitor integration and test execution and participation to material review board (MRB);
- chairing of daily meetings;
- preparation of test reports.

5.1.6.2 Management Tools

The major management tools that are utilized for the control of the AIV activities are presented below.

The verification activities will be performed by means of:

- Control and monitoring of the ESEO Satellite activities.
- Documents and reviews.

The objective is to check the completeness of the requirements contained in the specifications and delete possible duplications. The verification activities have also the purpose to evaluate the verification results on the basis of the information provided by the verification groups and the supporting functional department. A verification team decides upon the acceptance of verification or on further actions necessary to close a verification requirement.

The integration and test activities will be followed and monitored by quality control (QC) inspectors which will control:

- documentation and hardware / software availability;
- NCR / PVS status;
- performance of each step-by-step operation and its certification;
- filling of the integration Log-book;
- Work Items / Deviation Work Items completion

Test Readiness Review (TRR) and Post Test Review (PTR) are respectively used to declare the readiness for starting a test and to review the preliminary results after test completion. They are carried out during phase C/D at satellite level, prior and after each main integration and test activity.

In case of major non conformances/errors during verification activities, a Non Conformance Report is written and processed to assure correct actions and disposition through a material review board (MRB) in line with the product assurance (PA) project requirements.

At the end of the verification activities a delivery review board (DRB) will be held to prove that there is adequate documentary evidence to demonstrate that the product has satisfied all requirements.

5.2 Space Segment AIV

5.2.1 Satellite Assembly/Integration Plan

The satellite level integration starts when both the payloads and the platform elements are individually assembled and tested. Payloads and subsystems will be delivered at the satellite integration site, and the following activities will be then performed:

- mechanical and electrical interfaces verification;
- preliminary integration test;
- platform + payload mechanical integration;
- platform + payload electrical integration;
- integration test / functional verification;
- final integration of the solar array support structure and of the solar array;
- final integration of the thermal blankets (MLI);
- full functional test.

In the following the above listed activities are described.

Mechanical and Electrical interfaces verification All the interfaces between the platform and the payloads are verified, starting with a document verification (mechanical and electrical ICD check) followed by a verification by test of the electrical interfaces (signals and power voltage levels, signals timings).

Preliminary integration test The platform and payloads are electrically connected (possibly using the actual flight harness) prior to the mechanical integration, to perform a preliminary functional verification. This verification shall contain a reduced set of tests, but shall be accurate enough to confirm the possibility to proceed with the integration without risks. It is worth pointing out in fact, that there have been up to now no coupled interfaces and functional verification between the platform and the payloads.

Platform + Payloads mechanical integration The payloads are mechanically attached to the platform. This should not pose particular problems, since the correct coupling has been already verified on the structural model.

Platform + Payloads electrical integration The elements are connected with the flight harness, fixed at the end of the process.

Integration test / Functional verification This test is aimed at the final verification of the functionality of the coupled platform and instruments in the final flight configuration.

Final integration of the solar array support structure and of the solar array The solar array support structure and the solar panel with the deploying mechanism itself can be now integrated on the satellite. These are not integrated before to avoid possible damages to the solar panel.

Final integration of the thermal clothes (MLI) The MLI, if needed, is integrated in a specifically selected location.

Full functional test Finally, the integrated satellite is subject to a full functional test campaign, to verify that all the subsystems are working as expected. The result of this test session will also constitute the reference set against which the results of post environmental test results shall be compared.

5.2.1.1 Integration sequence

The satellite integration is done at the integration site (TBD) after the delivery of all S/S's and P/L's PFM (see table 4.3: ESEO Milestones). The arrival sequence of the equipment is mandatory since the following integration order must be respected:

On the integration stand (MGSE) the main structure and the adapter will be assembled. Subsequently the OBDH subsystem will be mounted on-board. Then in order ACS, EPS, TM/TC will be integrated. Finally also the payloads will be added. This sequence permits sequential tests on the satellite through its progressive integration phases with the available EGSE for each S/S and P/L. The TCS S/S will be added instead partially at the very end, as for the thermal cloth, and the remaining parts during the whole integration process where requested. The solar panel as well is added at the end when the satellite is partially closed. All elements will be at first connected mechanically and afterwards also electrically through the flight harness.

5.2.1.2 Integration constraints

The integration activities will take carefully into account cleanliness and humidity requirements by adopting special procedures, suited protections and envelopes. The integration process will be executed by a team of skilled specialists.

5.2.1.3 Transportation constraints

For the transport to the assembly site a dedicated container for each S/S will be used. Every team will be responsible for its own container and it will be developed and built according to the following main requirements:

- It has to minimize the transfer of transportation loads.

- It has to ensure a controlled clean environment for the spacecraft during transportation.
- It has to ensure a controlled clean environment for the spacecraft during storage.
- It has to ease the satellite packaging.
- It has to protect the satellite from accidental shocks.
- It has to protect the satellite from electrostatic charges.

Of course the same requirements are valid for the satellite container which will ship the space vehicle from the integration site to the launch site.

5.2.2 Test Plan, Criteria and Methods

According to the proto-flight approach of the ESEO satellite a particular test campaign is foreseen. After the qualification tests on EEMs and on the STM the acceptance testing is done on the PFM. That implies lower levels and duration for critical tests.

After a local, at each university, test campaign on the EEM with the relative EGSE, OGSE and possibly its MGSE every team will deliver all elements under its responsibility to the integration/verification site. This event corresponds to the milestone STM & EEM Delivery (table 4.3). Again here each EEM will be verified singularly with the corresponding GSE before proceeding with the integration of all elements. At the integration site the global test campaign can start while putting one after the other all EEM together. Since not all subsystems are assembled immediately a sequential arrival of the EEM's is allowed. The importance is the respect of the integration sequence described here:

- OBDH + ACS
- OBDH + ACS + EPS
- OBDH + ACS + EPS + TM/TC
- OBDH + ACS + EPS + TM/TC + all P/L's

Of course all of these steps will be monitored and directed from the Test Control Computer TCC. It has the duty to coordinate all EGSE's that simulate the missing S/S during the step by step integration. This test campaign ends with the QR.

In a similar way after the completion of each proto-flight S/S and P/L every university will carry out its local tests. After these all items will be delivered to the central facility for assembly, integration and verification; this event corresponds to the milestone Subsystem & P/L's Proto-Flight Models readiness for integration at system level. In this case as well the S/Ss don't need to be delivered at the same time. The only constraint to respect remains the integration sequence described above at system level. Now the global AIV campaign can start at the integration site.

First each single element will be checked for its integrity and functionality and secondly, following the same integration sequence as with the EEM, the space vehicle is assembled. Of course during the two stages the MCC will command and monitor the necessary GSE. This phase ends with the FAR.

5.2.3 EEM Test Program

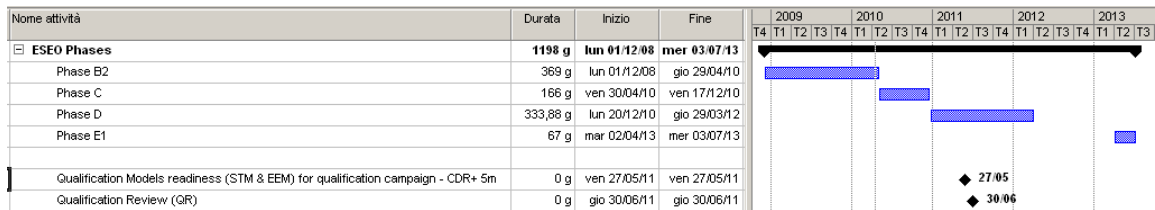


Figure 5.1: EEM and STM Reviews

5.2.3.1 EEM Test Program Objectives

The aim of the EEM test campaign is to verify functionality and integration compatibility of elements and between elements. Interfaces and software verification is executed as well and where necessary the rest of the satellite is simulated with the opportune EGSE. At this point the localization and the consequent amelioration of critical parameters is fundamental to avoid failures in further phases of the ESEO project.

5.2.3.2 EEM Satellite Tests

The following tests will be executed on the EEM.

5.2.3.2.1 Integrated System Test. The satellite is assembled and results in a global EEM connected to the TCC and the necessary EGSE. The integrated system test (IST) is a functional verification of the space vehicle. It is designed to verify that the performance of the ESEO spacecraft conforms with the specification requirements for correct operation in all operational modes, including back-up and degraded modes, and all transients. This test should be executed at the beginning and at the end of the test campaign. The IST activities should follow the mission's expected sequence of events and all critical parameters should be monitored in an appropriate database so that successive analyses can be done.

5.2.3.2.2 Short Functional Test In normal cases a full or complete functional test is done on the space vehicle after integration. For the ESEO mission again the idea is to minimize costs and time while respecting all European space standards to assure a well qualified product. Instead of doing a full functional test which normally would last two weeks one or more short functional tests can

be done. In these cases an accurate reduced selection of tests is applied so that all fundamental parameters can be investigated. The aim still remains the correct qualification of the space element.

5.2.3.2.3 System Validation Test The system validation test (SVT) is described in paragraph 5.4.1. At this point of the AIV process the SVT0 is applied.

5.2.4 STM Test Program

5.2.4.1 STM Test Program Objectives

The test campaign on the STM is part of the qualification campaign at the beginning of phase D. Its purpose is to verify that the structure will resist all loads during its operational life and that a proper temperature distribution is achieved during test simulations so that the operating environment of each S/S and P/L is the requested one. Proper margins are taken in consideration both for stresses and temperatures.

5.2.4.2 STM Satellite Tests

The following tests will be executed on the STM.

5.2.4.2.1 Mechanical Tests The following tests, with qualification levels, must be executed in the indicated order on the STM:

- alignment;
- physical properties;
- shock;
- acoustic;
- sinusoidal vibration.

Alignment. The check is executed on the STM with mass dummies of the inner equipment.

Physical properties. The space vehicle is submitted to measurement of its physical properties. Its mass, the location of the gravity center and the moments of inertia around its three coordinate axes are measured, not calculated. These parameters must be analyzed adequately for the launch and the orbit insertion configurations.

Shock. The purpose of the shock test is to demonstrate that the space vehicle withstands shock levels and frequency spectra as predicted for flight. The launch authority will provide the shock spectrum for this test. Other qualification test parameters are presented in table 5.1.

Acoustic. The test is executed in a suited facility with the qualification parameters described in table 5.1.

Sinusoidal vibration. The shaker will verify that the satellite is able to withstand the solicitations during launch. Table 5.1 describes the necessary test parameters.

5.2.4.2.2 Thermal Tests Both a thermal vacuum and a thermal balance test must be executed on the STM. All the inner S/S's and P/L's are here represented by thermal dummies.

The purpose of vacuum temperature cycling tests is to demonstrate that the element is capable to withstand the vacuum and thermal conditions encountered during the mission phases while remaining in the requirement limits.

On the other hand the thermal balance test should demonstrate the ability of the element to maintain the equipment's temperature inside the specified operational limits during all expected conditions of the mission. This test is used to validate the analytical thermal model of the element.

5.2.5 PFM Test Program

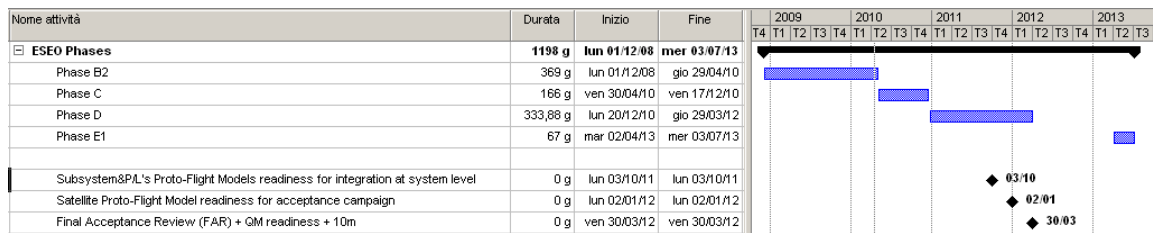


Figure 5.2: PFM Reviews

5.2.5.1 Test Objectives

In this test sequence, acting as a quality control, the objective is to demonstrate that the product is free of workmanship errors or manufacturing defects and is ready for operational use in conformance to the specification. All tests are executed on the same hardware and software that will fly. These tests should not create conditions that exceed safety margins or create modes of failure.

5.2.5.2 PFM Satellite Tests

5.2.5.2.1 Integrated System Test The satellite is completely assembled and integrated and is connected to the TCC and the necessary EGSE. The integrated system test (IST) is a functional verification of the space vehicle. It is designed to verify that the performance of the ESEO spacecraft conforms with the specification requirements for correct operation in all operational modes, including back-up and degraded modes, and all transients. This test should be executed at the beginning and

at the end of the test campaign. The IST activities should follow the mission's expected sequence of events and all critical parameters should be monitored in an appropriate database so that successive analyses can be done.

Not only electronic and electric devices are checked, but also the mechanical connections are verified before and after each test.

5.2.5.2.2 EMC Test Due to the PFM approach for the ESEO project no prototype model was available for electromagnetical compatibility testing. For this reason this test is executed on the PFM space system after integration.

The purpose of this test is to determine whether any space vehicle operation can be adversely affected by electromagnetic interference from external sources, and whether the space vehicle itself emits any electromagnetical signal that can adversely affect its own operations, those of its payloads, or of external elements.

The space vehicle shall be subjected to electromagnetic susceptibility and emission tests for the launch configuration and for the most critical and sensitive modes of operation.

5.2.5.2.3 Short Functional Test In normal cases a full or complete functional test is done on the space vehicle after integration. For the ESEO mission again the idea is to minimize costs and time while respecting all European space standards to assure a well qualified product. Instead of doing a full functional test which normally would last a minimum of two weeks, one or more short functional tests can be done. In these cases an accurate reduced selection of tests is applied so that all verification sectors can be investigated. The aim still remains the correct qualification of the space element.

5.2.5.2.4 System Validation Test The system validation test (SVT) is exhaustively described in paragraph 5.5.1.

5.2.5.2.5 Mechanical Test The following tests must be executed, at protoflight levels, in the indicated order on the space vehicle PFM:

- alignment;
- physical properties;
- shock;
- acoustic;
- sinusoidal vibration.

Alignment. The alignment measurements must be verified for all optical equipments. Every item must not exceed the admitted tolerances.

Physical properties. The space vehicle is submitted to measurement of its physical properties. Its mass, the location of the gravity center and the moments of inertia around its three coordinate axes are measured, not calculated. These parameters must be analyzed adequately for the launch and the orbit insertion configurations.

Shock. For the shock tests only 2 repetitions of activated events shall be performed in accordance with the PFM philosophy. The shock spectrum will be provided by the launch authority.

Acoustic. Acoustic tests are conducted in the acoustic chamber with the spacecraft in launch configuration on a support simulating the dynamic flight conditions but being low frequency decoupled from the chamber equipment. All equipment that operates during launch shall be operated and monitored during the tests. The qualification test spectrum shall exceed the flight spectrum by 3 dB throughout the frequency range, unless specified differently in the respective launcher user's manual. The test duration depends on the fatigue equivalent duration in flight, which depends on the launcher, multiplied by a factor of 2. The test duration shall be not less than one minute, in general it lasts about 2 minutes.

Sinusoidal vibration. The vibration test parameters are described in table 5.1.

5.2.5.2.6 Thermal Test In this test section, acting as a quality control, the objective is to demonstrate that the product is free of workmanship errors or manufacturing defects and is ready for operational use in conformance to specification. All tests are executed on the same hardware and software that will fly. These tests should not create conditions that exceed safety margins or create modes of failure.

5.2.6 Packing and Shipping

The packing activities will be carried out each time the satellite needs to be moved from the integration facility to the test facility. The packing activities will take carefully into account cleanliness, humidity and transportation requirements by adopting special procedures, suited protection and envelopes. Dedicated procedures will be provided for handling instructions before and after packing and for packing/unpacking operations. The satellite will be closed in an appropriate transport container; the container will be adequate to protect the satellite from damages due to transport environment when using commercial transportation means. The transport container is part of the MGSE items and it will be manufactured according to the requirements and to the design, to be produced during phase B.

The satellite PFM shipping is foreseen for the following movements:

- From the integration site to the test facilities, and back
- From the integration site to the launch site

5.3 Ground Segment AIV

As well as the space segment the ground segment must be subjected to an adequate qualification and acceptance campaign. Nevertheless the approach differs partially from the AIV for “flight” hardware since post-launch maintenance and replacement of damaged elements is always possible. Thus, many critical space vehicle tests are not relevant for ground hardware, as for example environmental testing.

According to the ground segment architecture described in table 3.4 for each component a detailed AIV should be developed.

For the ground segment the items which should be prepared and ready for use at first are all the components of the GSE. This because they will be required for the tests each team/university will do on their S/S or P/L. These elements should be developed in parallel to the subsystem during the qualification phase in order to allow all the necessary test activities before delivering all EEM and the STM to the central test facility (TBD). In the acceptance campaign they will be required as well. A problem here arises since during the MAIT process of the proto-flight model of each subsystem and payload the GSE has already been delivered to the central facility. Two alternatives can here occur:

- Each GSE is returned to the home university for the local acceptance campaign. Then again both the S/S or P/L and the GSE are delivered for the global acceptance campaign to the central test facility.
- Otherwise the proto-flight models are prepared by the universities which deliver them to the central facility where all necessary tests are then executed with the aid of the GSE. In this case no local tests can be done in the laboratories of the universities.

The choice between the two strategies will be defined in a future step of the project.

For all the components of the Mission Operation Segment each part should be subjected to an individual test campaign. All functional and performance requirements must be verified and where necessary all S/W tasks should be performed to identify critical parameters. A progressive integration of all elements should follow building up the complete ground segment but only after the individual validation of each component. The sequential integration shall demonstrate that two or more assembled subsystems are capable of functioning together. In some cases, if needed, specific S/W simulators should be used before establishing the real connections between two or more hardware interfaces in order to avoid failures which could possibly damage the components.

For the Ground seg AIV the following test phases are foreseen

- Ground segment S/S acceptance test
- Ground segment integration test

- Operations validation tests
- Ground segment mission readiness test

Ground segment subsystem acceptance tests

The objective of this phase is to establish confidence and confirm the performance of each individual subsystem of the GS. This refers to the completeness of the equipment with respect to functional, performance and interface requirements. The element should fulfil all specified functional and performance requirements in the intended operational environment. Possibly specifically developed test hardware and software are used in the whole verification process. At S/W level tests must be conducted by running and evaluating specific tasks as previously defined with the S/W user.

Ground segment integration tests

The objective of the integration test is to verify that two or more assembled subsystems are capable of functioning together, satisfying all relevant interface requirements. Integration testing consists in a sequential assembly of all elements which were themselves previously verified in terms of functional and interface performance. If needed, before connecting hardware interfaces, software can be used to simulate the connection between elements to avoid possible physical damage.

Operations validation tests

Operations validation tests are used to validate parts or the whole GS. They are meant to verify the correct functioning of parts or of the complete system. The objective is to check the correctness of the operations control and monitoring software in relation to the space vehicle. The robustness and integrity of hardware and software are verified as well for all operative and back-up modes. These tests are also intended to verify the procedural content of the flight operation plan (FOP) and to confirm functional and performance integrity of the ground stations and with them in terms of communications interfaces. All tests must be executed in a realistic operational environment in order to meet specific operational conditions. Of course subsystem acceptance tests must be complete satisfactorily before proceeding with integration and the operations validation campaign shall start only after successful integration testing.

Ground segment mission readiness test

The objective of the GS readiness test is to confirm the operational readiness status of the GS, in particular the control system and the communication networks both in the nominal and in the back-up modes. Extended data flow tests should be executed, as well as specific on-station performance checks.

5.4 System Verification Procedures

The system verification process will take into account more steps. Each verification method is described in the next paragraphs.

5.4.1 System Validation Test

The final step of the AIV and Test activity is the System Validation Test (SVT). This test will verify the capability of the integrated ground segment, together with the space segment, to perform all functions necessary to operate the ESEO mission and to fulfill its requirements.

The focus of the SVT is to verify the system performances and the data exchange between the space segment and ground segment. In order to perform these tests the system shall be integrated. At system level the integration procedure before flight consists of various physical links between the satellite and the ground station and the verification of their functionality. All the system interfaces (spacecraft to ground stations and among ground segment elements) must be checked with the dedicated documentation. Once these links are established and verified all the satellite and ground segment functionalities are tested with proper procedures. The SVT will verify the system response in simulated conditions that are as much as possible representative of the operating scenario.

The SVT will exercise all system interfaces:

- Spacecraft-ground stations interface: both RF interface (communication link) and data interface (telemetry and telecommand formats and parameters)
- Ground segment interfaces: ground station-MCC and MCC-internet.

As said above, the SVT will include a RF compatibility verification, with the aim of validate the RF interface between the ESEO spacecraft and the Ground Station. The test will be performed with the PFM satellite, and with a specially prepared test bench which is a high fidelity representation of the ground station. The test will verify the compatibility of RF modulations, levels, frequencies, and link budgets.

In the ESEO system verification process three SVT sessions are foreseen, a pre-SVT (SVT0), SVT1 and SVT2. SVT0 will be a preliminary check of the telemetry and telecommand interfaces at baseband level. No RF compatibility test will be performed during this session, thus no RF equipment will be used.

SVT0 will be performed with the following configuration:

- OBDH EM,
- Satellite EGSE,
- Ground Station Baseband equipment,
- MCC equipment.

All the equipment can be located in a single location.

SVT1 and SVT2 will be performed with the following configuration:

At the satellite integration site:

- Satellite PFM,
- Satellite EGSE,
- Ground station representative RF equipment,
- Ground station representative baseband equipment.

At the MCC location:

- Mission Control Computer equipment in the final configuration,
- A communication link shall be established between the two locations, capable to permit the real time exchange of commands and telemetry data between the two locations.

The SVT1 and SVT2 sessions will be combined with the SOVT.

5.4.2 System Rehearsal Test

After all system performances are verified, a second test will be performed in order to check and verify the operational procedure which shall be performed between the satellite preparation in the pre-launch phase and the acquisition of a stable and safe condition of the satellite with a communication link between the satellite and the ground segment. This test will be a simulation of all the events which will take from the satellite functional check before the launch to the satellite in-orbit contact, check and preparation before the commissioning phase.

5.4.3 SOVT

The System Operation Verification Test allows to evaluate and if necessary to improve operative procedures, and is the final training phase for the operative personnel. The test must be performed with the PFM satellite, and with a specially prepared test bench which is a high fidelity representation of the ground stations. The test will verify the compatibility of RF modulations, levels, frequencies, and link budgets.

5.4.4 Interfaces Check

The interfaces check between satellite and launcher is normally executed in two steps:

- During satellite integration
- After satellite integration

During the Satellite integration, a *Separation Test* between satellite and launcher will be carried out to verify the mechanical interfaces between the two elements and to verify that the satellite can withstand the loads induced by the separation event without any damage and/or degradation. This test will be carried out by means of the Satellite STM, representative of mechanical interfaces, mass, CoG and MoI of the Satellite.

During integration, an *Umbilical Interfaces Verification Test* will be carried out, in order to demonstrate the correct operation of Umbilical Interfaces in the configuration that will be used during launch preparation operations.

During the Satellite integration, an EGSE Remote Interface Verification test will be carried out between Satellite EGSE and Satellite EGSE Test Control Computer, in order to demonstrate the correct remote control and monitoring capabilities of Satellite Test Control Computer over Satellite EGSE during the final launch operations, when operators are not allowed to remain in Checkout Terminal Room where the Satellite EGSE is placed and the control is moved to the *Spacecraft Preparation Facility* where the Satellite EGSE Test Control Computer is placed.

After the Satellite integration, the following tests between satellite and launcher will be carried out: o

- Umbilical Interface Verification
- EGSE Remote Interface Verification

The Umbilical Interfaces Verification test already carried out during satellite integration will be repeated with the real Umbilical Harness at the beginning of launch campaign in order to verify the correct behaviour of Umbilical Interfaces between Satellite and Satellite EGSE.

The EGSE Remote Interface Verification test already carried out during Satellite integration will be repeated with the real harness between Checkout Terminal Room and Spacecraft Preparation Facility at the beginning of launch campaign, in order to verify the satellite Test Control Computer capabilities to fully support the final launch operation phases, when no operators are allowed in Checkout Terminal Room where satellite EGSE is placed.

6 Conclusion

With the end of this thesis ESEO enters the final steps of phase B2. The content developed in this document is part of the official DDP and AIV Plan of the ESEO mission for the PDR review. The first issue of both documents will be delivered to ESA in May 2010. Both papers will be then updated during phase C leading to the final version for the CDR review.

The work developed together with CGS and here presented is a crucial step in the definition of the work flow of the project. It gives each student and member of the ESEO project a high level overview which enables a fast identification of deadlines and duties every team is responsible for in the AIV process. A successful AIV processing, as a matter of fact, gives the authorization to proceed from one phase to the next one and so to continue in the project execution. For this reason both DDP and AIV Plan are fundamental in a project, especially the AIV document. It clearly summarises for all participants all crucial events in the work flow of a project's life cycle. This is a very important aspect since a single document counts as guideline for all involved personnel and an efficient operating structure is the key for success in projects that are financed with great sum of public European money.

In the elaboration/composition of the thesis the application of ECSS standards has been necessary. These are built upon experience gained in the past decades by the European space community. What was found, principally in relation to the standards for *Verification* and *Testing*, is a repetition of contents: test and verification methodologies are first shortly introduced and then deeper analyzed and described in dedicated paragraphs. Here, sometimes, topics are not well separated or it is difficult to identify the proper order of events that must be followed due to excessive text explanations that could be avoided through simple and more effective tables or diagrams. These are already present but often remain in the background. A synthetic version of standards could therefore simplify the interaction of the user with ECSS and fasten procedures while still preserving the quality of the guidelines.

Another consideration can be done regarding ECSS: the ESEO mission is fully compliant with the European standards. No differences between a commercial satellite and the educational mission can be specified apart from longer timings due to students engagement.

A last aspect that may be underlined, is the introduction of innovative techniques, as an ECSS standard or as an alternative path, in the development of a space project. At the present time, as already introduced in paragraph 2.3, a common basis for simulation models in the development of a space program could be of great advantage to fasten events and to minimize costs. This direction should be strongly supported by ESA to make space even more accessible.

During the realisation of this work about DDP and AIV plans the central position of CGS has been very important. At the beginning the idea for the development of ESEO relayed on the basis of a rotating responsibility: in sequence all universities had to lead the project, thus controlling and collecting materials from other teams. This approach was soon identified to be very dispersive and required a great effort from ESA who decided then in 2008 for an external institution, CGS, to guide the project. The leader position of CGS is now well appreciated. All updates, changes and corrections on the work flow come directly from CGS. All teams respond directly to a single project leader, a fact that avoids misunderstandings and incomprehensions if compared to the previous rotating leadership position. Furthermore the active use of an internet server for up and downloading of reports, models and graphics is of advantage for all ESEO teams and contributes to their successful cooperation. The leadership of a company such as CGS is important from another point of view. Students can now acquire work experience in a real space company through dedicated internships, a fact that with the previous organisation was not possible. That is a fact that increases considerably the quality of the educational mission.

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