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INPE-9578-PRE/5208

PILOT PROJECT FOR THE ESTABLISHMENT OF A DEVELOPMENT PROCESS FOR FUTURE SPACE SYSTEMS AT INPE

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Paper presented at the 7th International Symposium on Space Operations and Ground Data Systems – SPACE OPS 2002 – Houston-USA, October 2002.

INPE
São José dos Campos
2003

PILOT PROJECT FOR THE ESTABLISHMENT OF A DEVELOPMENT PROCESS FOR FUTURE SPACE SYSTEMS AT INPE

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ABSTRACT

This work presents a customization of the European Cooperation for Space Standardization (ECSS) standards for defining a development process for the ground segment of the FBM project. The FBM project consists of a scientific/technological space mission developed in cooperation between Brazil and France. In this project, the development of the ground control system and the in-flight satellite operation are under INPE responsibility. For the in-house developed ground systems, a process that establishes project phases, milestones, activities, input and the output documents/products to be generated at each phase, was defined, taking into account the existing resources and background at INPE. This paper focuses on the aspects of requirements management, configuration management, verification and validation . Moreover, it points out the COTS tools adopted for assisting in the product quality assurance activities. The process, defined in the context of the FBM ground segment, is being considered as a pilot project . It is expected that, as a consequence of its good results, in the long term, it will be adopted in all future missions.

Keywords: ground segment, ECSS standard, development process.

1. INTRODUCTION

The French-Brazilian Micro-satellite (FBM) project consists of a space mission developed by Brazil and France that aims the developing, launching and operating of a scientific/technological micro-satellite carrying experiments from both countries. In this cooperative project between INPE and CNES, the Ground Segment, among other tasks, is under INPE's responsibility.

Due to the increasing pressure to reduce costs and the complexity of the systems, the adoption of a well established process for the systems development is more and more necessary. In this context, the development team was led to formalize a process based on the ECSS standards [1].

Nevertheless, the extensive coverage of the ECSS standards and the tight schedule has led the process to be not fully compliant with the standard and to be incrementally implemented. Its first version covers the Ground Segment Engineering general context and focuses on the needs for software systems development, as most of the ground systems are software intensive.

The process comprises a Ground System software life cycle nested to the Ground Segment life cycle. The phases, milestones and the input/output criteria characterize the life cycle at the different levels of the ground segment decomposition, as shown in section 2.

In order to assure the quality of the systems to be developed, the process is supported by the following areas: requirements management, configuration management and verification & validation (V&V), which are presented in sections 3, 4 and 5 respectively. Conclusion and remarks are drawn in section 6.

2. THE DEVELOPMENT PROCESS

The process was based mainly on the ECSS standards which has being a very good reference for the general understanding of the particularities of the space systems. Besides that, it provides a framework to define and implement a space project.

The decomposition of the space system in hierarchical levels established in the Development Process of the FBM is illustrated in Figure 1.

The systems of a space mission are classically broken into Space and Ground Segments. The Space Segment is related to the conception, design, production, integration, verification and validation of all spacecraft systems, while the Ground Segment is in charge of preparing the environment, designing, implementing, integrating, verifying and validating the systems to remotely monitor and control the spacecraft as well as to explore and disseminate the mission data.

The systems comprising the Ground Segment are named **Ground Systems** and the software and the hardware products composing each Ground System are referred as **subsystems** or **elements**.

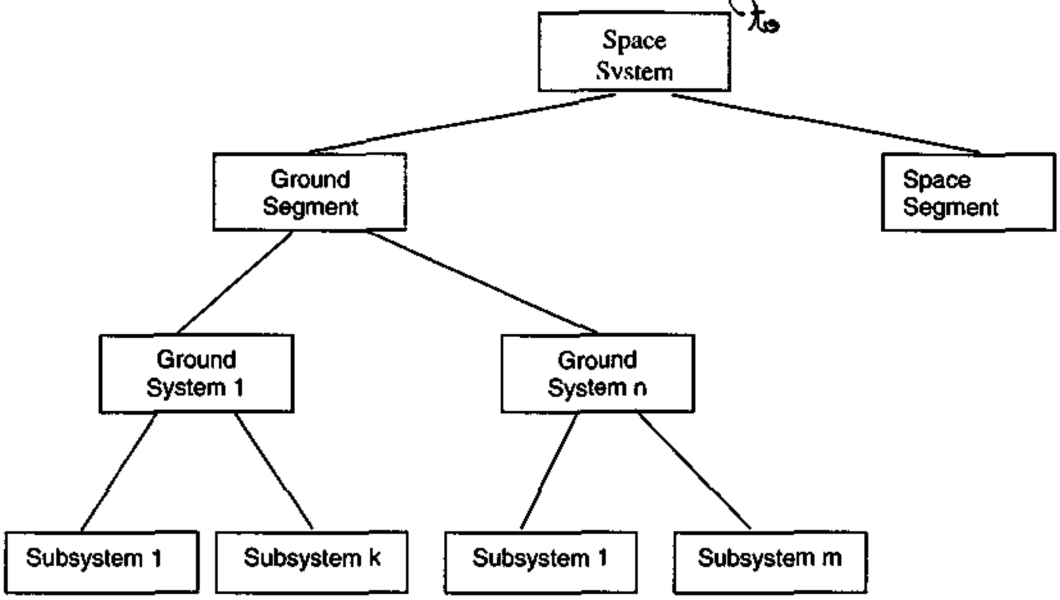

Figure 1 – Diagram of Hierarchical Levels of a FBM Space System

The ground systems of the FBM project are the Control Center System, the Natal Ground Station System, the Brazilian Mission Center System, the French Mission Center System, the Satellite Model Data Base and the Ground Communication Network. The system testing tools, viz. the Satellite Simulator and the Suitcase are also at the ground system level.

The ground segment project comprises the following five main activities, illustrated in figure 2: Ground Systems Development; Operations Preparation; Ground Segment Integration; Technical Validation and Operational Validation. These activities are conducted over two parallel main domains, the Ground Systems Development and the Operations Preparation and are followed by the verification and validation activities [3].

The Operations Preparation activities include the generation of a set of documents viz., Mission Operation Concept (MOC), Operational Validation Plan, Operators Training Plan, Flight Operations Plan (FOP), Ground Operations Plan (GOP) and Ground Segment Operations Schedule. The activity of training the satellite operation team also comprise the Operation Preparation.

The development of each Ground System includes the activities of project, production, integration and test. If the Ground System is broken into subsystems, then each subsystem, hardware and/or software, has also the activities of project, production, integration and test.

When the ground systems are ready and accepted, the Ground Segment Integration phase starts. Following this phase, the Technical Validation is executed, including the integration between ground and space segments. The Operational Validation closes the activities of the Ground Segment development, meaning that all ground systems are ready to assume the responsibility of the satellite operation.

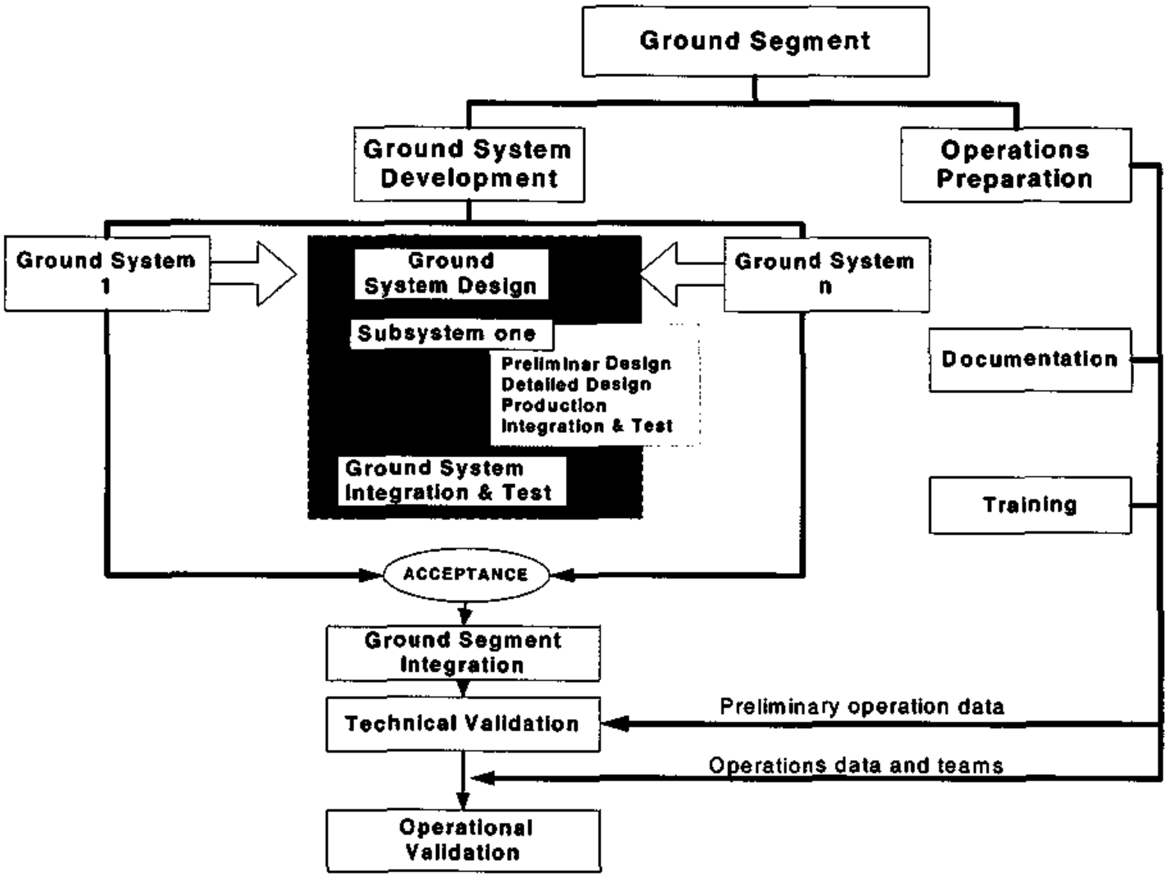

Figure 2 – Ground Segment Development Activities

2.1. PHASES AND ACTIVITIES

The top level phases of the Ground Segment Development Process are the commonly designated mission phases, e.g., 0/ A, B, C, D, from conception to validation. The operation and maintenance phases, E and F respectively, are not considered in the present process. Table 1 summarizes the Ground Segment activities and reviews that should be performed during the mission development. One phase begins only after the success of a formal review of the previous phase. The development phases of a intensive Ground System software, mainly, I-a, I-b, II, III-a, III-b, IV and the respective reviews, that occur at the end of the respective phase, are summarized in Table 2. The output of phases I-a, I-b, II, III-a and the results of their respective reviews, GSPDR, SRR, SPDR and SCDR are the inputs to the Ground Segment Critical Design Review, the GCDR. Figure 3 presents an overview of all phases and reviews from both levels: Ground Segment and Ground System, highlighting the overlaps among them. It may be observed that to start the phase D2 the ground systems must be already validated and accepted, then they are ready for the Ground Segment integration and tests. In the FBM software development process some additional phases and reviews were included. Figure 4 shows a parallel between the software development phases and reviews proposed by the ECSS standards [4] and those established for FBM software development.

Table 1 – Ground Segment Activities/Reviews of the Mission Phases

Phase / Review	Description	Activities /Review objective
0/A	Mission analysis and feasibility	-Identify the characteristics, constraints, concepts and evaluate the mission feasibility of Ground Segment and satellite operations. -Define preliminary space to ground interface -Define preliminary Ground Segment architecture
GRR	**Ground Segment Requirements Review**	Select a preliminary Ground. Segment baseline
B	Ground Segment Preliminary Design. Operation concepts consolidation.	-Define the Ground Segment requirements and its baseline, -Consolidate the operations concepts. -Define the ground systems and the system testing tools
GPDR	**Ground Segment Preliminary Design Review**	Approve the Ground Segment baseline and select the main suppliers.
C	Ground Segment Detailed Design Operations Preliminary Plans.	-Identify subsystems comprising each ground system - Prepare a initial version of Flight Operation Plan, operation team training Plan and operational validation document.
GCDR	**Ground Segment Critical Design Review**	- Approve specification, organization, planning, costs and quality of the Ground Segment Detailed Design - Check compatibility of external and internal interfaces - Check conformance with Ground systems
D	Production, Verification and Validation (V&V) of the Ground Systems	
D1	Production	- Implement the subsystems - Integrate & test each Ground System
D2	Ground Segment Integration Preliminary version of operational procedures and mission data Technical V&V	- Integrate Ground Segment - Populate the Satellite Model Data Base - Validate operational procedures - Execute Technical V&V
GTVVR	**Ground Segment Technical Verification & Validation Review**	- Assure that Ground Segment conforms to its specification
D3	Operation team training Conclusion of the Flight Operation Plan Operational Validation	- Conclude the training plan - Train operating team - Conclude the FOP & operation schedules - Validate all Ground Segment: systems and operations
OVR	**Operational Validation Review**	- Assure the full readiness of the Ground Segment for in-orbit satellite operation.

Table 2 – Ground Systems and Software Products Phases/Activities/Reviews

Main Phase/ Review	Software phase/ Review	Description	Activities /Review objective
C	I-a	Ground System Preliminary Design	- Analyze system requirements, - Decompose the system in software subsystems - Define the interfaces among the software subsystems
	GSPDR	**Ground System Preliminary Design Review**	

	I-b	Requirements definition of software subsystem	- Define the subsystem requirements from the user´s point of view
	SRR	**Subsystem Requirement Review**	
	II	Preliminary Design of Software Subsystem	- Analyze the requirements - Design the high level architecture (logical and physical) - Perform the Data Base logical design - Define the Interfaces among the modules
GSCDR	**SPDR**	**Preliminary Design Review of Subsystem**	
D1	**III-a**	Detailed Design Review of Software Subsystem	- Design each module
	SCDR	**Critical Design Review of Subsystem**	
	III-b	Production	- Perform the coding - Test the software units - Integrate and test the software subsystems - Apply the acceptance test to the subsystem
	SATR	**Subsystem Acceptance Test Review**	
	IV	Ground System Integration and Test	- Integrate the ground system - Technically Validate the ground system - Apply the acceptance test on the ground system
	GSVR	**Ground System Technical Validation Review**	
	GSAR	**Ground System Acceptance Review**	

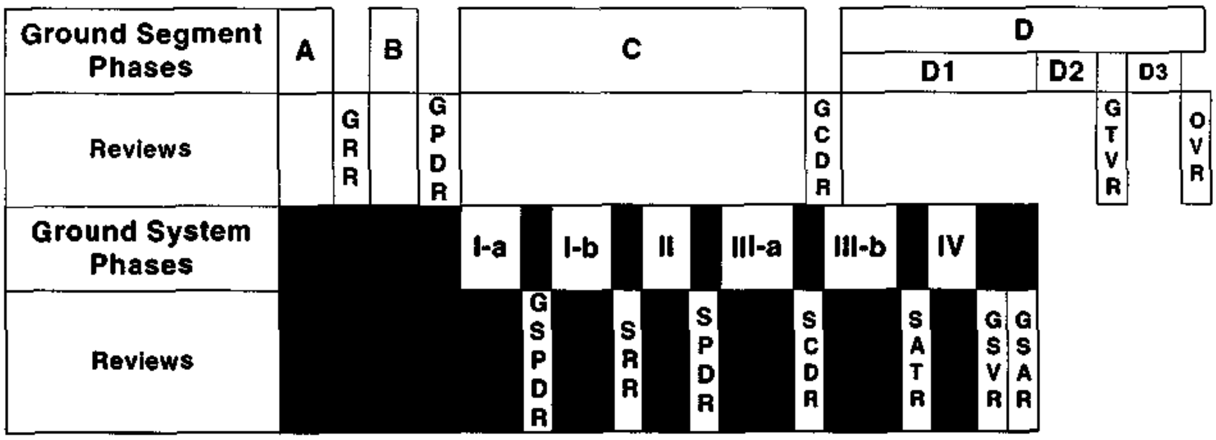

Figure 3 - Ground Segment and Ground System Phases/Reviews

ECSS Software Phases	Requirements Engineering						Design Engineering				Software V&V		
Reviews				SRR		PDR				CDR		QR	AR
Ground System Phases	I-a		I-b		II		III-a		III-b		IV		
Reviews		GSPDR		SRR		SPDR		SCDR		SATR		GSVR	GSAR

Figure 4 - Ground System and ECSS Software phases

3. REQUIREMENTS MANAGEMENT

The ground segment development success is closely related to insuring that the generated systems comply with the mission requirements. Due to this fact the requirements management is invaluable to support the Quality Assurance of the generated products.

In order to correctly generate a system it is necessary to insure, at least, that:

- each requirement of a high level component is met by a low level component,
- during the design of a component each requirement is addressed to one sub-level component,
- each component is originated from at least one requirement.

Moreover, the management of the relationship among the several information levels is essential to evaluate the impact (work volume) whenever changes in requirements or design are requested.

The requirements management process will be composed of three activities: requirement identification, traceability policies and requirement change management, which will be supported by the Rational RequisitePro[tm] tool.

The requirement identification consists of associating one unique identification to each requirement and to each component generated during the several design levels (systems, subsystems, elements).

The requirements traceability will be implemented from the Ground Segment Level to the software elements level. The whole process was structured to support traceability in horizontal and vertical levels. Vertical traceability is covered between requirements from one level to the requirements of both the upper and lower levels. Horizontal traceability is covered over requirement, design components and interfaces. The traceability policies, illustrated in figure 5, shows the coverage of the following aspects: Requirements x Requirements; Requirements x Design; and Interfaces x Design.

The Requirements x Requirements traceability allows to verify that all high level requirements are covered by lower level requirements and that each lower level requirement is originated from a higher level requirement.

The Requirements x Design traceability allows to verify that all requirements are covered in the design solution and that the design solution fulfills, at least, one requirement.

The aim of the Design x Interfaces traceability is to demonstrate that all the high level interface requirements are covered in the next lower level design solution and that the design solution fulfills all the interface requirements.

Related to the requirement change management, a formal process was defined. This process is composed of: problem analysis, change impact analysis and change implementation in case of approval.

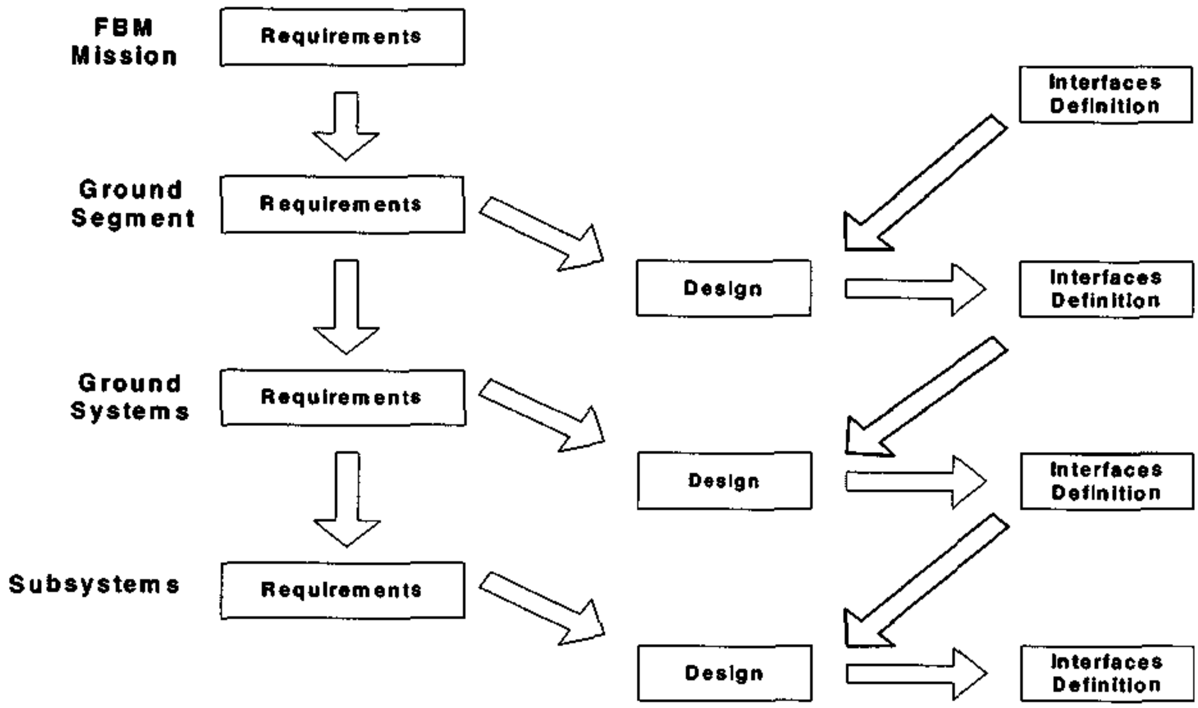

Figure 5 – Traceability levels

4. CONFIGURATION MANAGEMENT

As changes along the systems development are unavoidable, a Configuration Management process is needed to identify, manage and keep control of the product changes (softwares and documents).

The products generated at each development phase are reviewed, and, in case of approval, they are put under configuration control, at the end of that phase. Whenever a controlled product has to be modified, the following formal process will be accomplished:

- Problem identification and change request
- Change impact analysis and definition of the affected products
- Change request approval
- Change execution
- Change review
- Creation of new version of the modified products

To support the Configuration Management process of the documents (which includes the following activities: product tree creation, document version control and changes, and reviews workflow management), the Directa™ tool will be used.

The software elements version control and the software products generation will be performed using the Microsoft Visual Source Safe™ and Microsoft Visual C++ 6.0™ tools in an integrated way.

The change impact evaluation will be performed with the aid of both the traceability matrices generated by the Rational RequisitePro ™ tool and the dependency tracking facilities available in Microsoft Visual Source Safe™ and Microsoft Visual C++ 6.0™ tools.

5. VERIFICATION AND VALIDATION

The V&V aims at achieving the maximum reuse of the testing tools and the adoption of cost effective techniques in order to assure the required quality of the software products of the FBM Ground Segment with a minimum effort.

By *Verification* we mean to revise, inspect, test or audit a process or services and/or documents in order to evaluate if they conforms to the specified requirement [6]. And, by V*alidation*, to evaluate the final product conformance to the user specified requirements [2].

The activities of the V&V process run in parallel to all phases of the development process. The process starts with the Ground Segment requirement specification and proceeds until the code lines of the subsystem software units, so it comprises different stages based on the concept of bottom-up building-blocks. In the process presented here, two verification methods will be used: reviews and tests, whereas only tests are used as the validation method.

The reviews comprise static technical analysis over all generated documents. The set of the established formal reviews, at the end of each phase, are presented in section 2. Five reviews are expected to cover the mission phases, as shown in Table 1 and, at Ground System level, seven other formal reviews are planned, as shown in Table 2.

Relative to the tests, in general there will be three kind of tests: unit, integration and acceptance or validation tests to be applied to each level of details, such as ground segment, ground system and subsystem.

The life cicle of the tests defined for the FBM Ground Segment sugests a development in "V. The planning of the tests is prepared at each phase of the development, in a top-down strategy. However, the test execution and results report are applied and generated respectively, in a bottom-up strategy.

An overview of all test phases, from the Ground Segment to the subsystem level is illustrated in Figure 6. At the left side, it is indicated the set of documents generated in one phase (baseline): GRRD, GPDRD, etc. which serve as the basis to test cases especification and planning. At the right side, the arrows indicated the produts states at the end of each phase, from compiled software units to the Ground Segment ready for in-flight operation. The minimal criterium for testing is to cover all the specified requirements for functional and performance tests, all interfaces for integration tests and all operational procedures for operational tests. The unit test corresponds to white-box test, and in which the minimal criterium will be established case by case, because of the particularities of each implementation. For object-oriented subsystems, some guidelines have being prepared based on the work presented in [5].

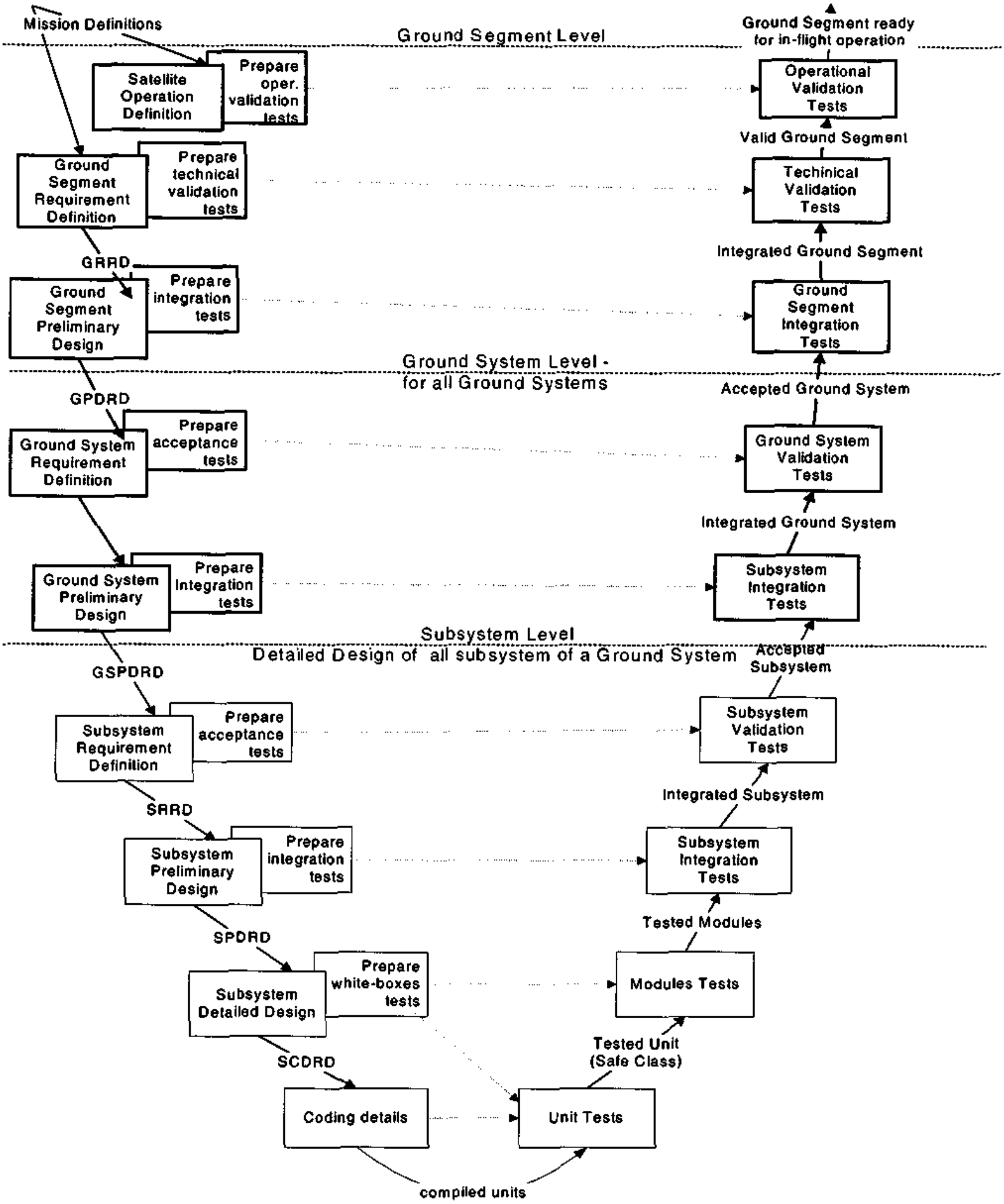

Figure 6 - Overview of the Ground Segment Test Phases

6. CONCLUSION

During the definition of the FBM Ground Segment development process it was noticed that despite the ECSS standards provide a good orientation and allow to establish a development culture in the team, they are not able to be directly used and a lot of work is necessary to tailor them.

Due this difficult, a minimal development process was established for the FBM Ground Segment products quality assurance, respecting the Mission schedule and costs. This process comprises the definition of a Ground Segment development life cycle. For each development process phase was defined the inputs, tasks and outputs based on a customer-supplier relationship. This process is supported by requirements management, configuration management and V&V activities.

The process, defined in the context of the FBM ground segment, is being considered as a pilot project. It is expected that, as a consequence of its good results, in the long term, it will be adopted in future missions. New areas will be incorporated along the time, gradually incrementing the process, respecting the team culture and feedback. Future improvement are envisioned in the areas such as: metrics and process management.

ACKNOWLEDGEMENT

We would like to thank Dr. Himilcon Carvalho , Mr. Wilson Yamagutti and Dr. Plínio Tissi for their suggestions to improve this work. All people participating in the ground systems development are likewise acknowledged.

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Número

DSS-002/2002

Titulo - 1053

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Palavras Chave

ground segment, ECSS standard, development process.

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9578

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