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FBM GROUND SEGMENT AND OPERATIONS CONCEPT

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ABSTRACT

This paper presents the FBM Ground Segment architecture and describes its development process, along with the Mission Operations Concept, adopted for the FBM joint program. The French-Brazilian Micro-satellite (FBM) Mission is a cooperative program between the CNES (France) and INPE (Brazil). This mission consists in developing, launching, and controlling a scientific/technologic micro-satellite as well as the payload data dissemination. The Ground Segment is being developed under the directive of maximum re-use of existing systems in Brazil, such as CBERS (China-Brazil Earth Resources Satellite), SACI (Scientific Applications Satellite). In addition, a maximum commonality between processes and elements of AIT and operations was sought for risk and costs reduction reasons. For example, the *Satellite Model Data-Base*, which gathers all system information is used by SCC, AIT, on-board S/W, and Satellite Simulator. The telecommand software of the Proteus (French Multi-mission Platform), will be used in both EGSE and SCC. So that both programs, French and Brazilian, could benefit from already developed and tested modules for their ground sub-systems. Scheduled to be launched by early 2004, FBM aims at being a valuable tool for the scientific and technological communities, and provides a rich framework of technical cooperation between both countries.

INTRODUCTION

The French-Brazilian Microsatellite (FBM) is a cooperative program between the French Space Agency (CNES) and the Brazilian National Institute for Space Research (INPE), aiming at the development of a scientific microsatellite and its ground segment. Five Brazilian and four French technological and scientific experiments will fly onboard the FBM.

Regarding task division, the System Activities, Launch, Operations, Ground Segment and the Satellite's Power Supply, Structure, and Thermal Control Subsystem are under INPE's responsibility, whilst the Onboard Data Handling, Telemetry and Telecommand and the Attitude Control functional chains are under CNES responsibility.

The spacecraft main characteristics are:

- The platform is three axis stabilized providing 0.5° of pointing accuracy and up to 30W (mean power) to the payload module.
- The payload comprises 9 experiments from French and Brazilian scientific institutions.

This paper presents the Ground Segment architecture, along with Operations concept and the development process adopted for FBM on which the constrains and the cooperative relationship has to be taken into account. Many of the concepts for the mission organization was based in the ECSS standards[1].

GROUND SEGMENT ARCHITECTURE

The Ground Segment is composed of the Mission Control Systems, the Ground Station System (GS), the Satellite Model Data Base System (FBMBDS) and the Network Communication System (NET) as shown in figure 1.

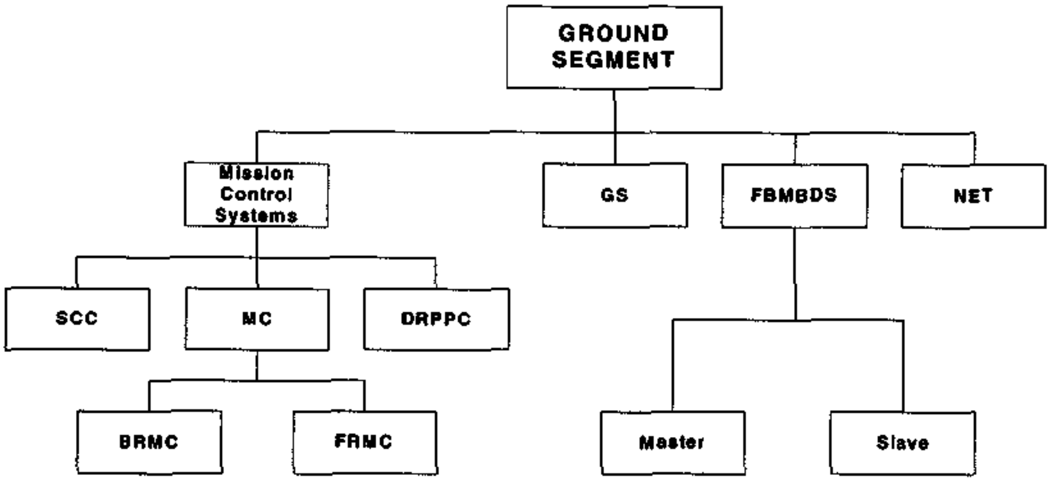

Figure 1 – Ground Segment Systems

The Mission Control System comprises the following elements required to control the mission: Satellite Control Center System (SCC), Mission Centers (MC) and Data Remote Processing Personnel Computer (DRPPC).

The SCC will be located in São José dos Campos, Brazil taking advantage of the existing infrastructure. It is responsible for: establishing and managing the System schedule, preparing the On-board and Ground Work Plans, executing the Ground Work Plan and storing temporarily the payload data.

This mission has two MCs: the Brazilian Mission Center (BrMC), located in São José dos Campos, responsible for the interface with the Brazilian Principle Investigators (BPI) and the French Mission Center (FrMC), located in Toulouse, responsible for the interface with the French Principle Investigators (FPI). Both MCs aims at preparing and monitoring the execution of the Payload Work Plan and archiving and making available the payload data for the BPI's and the FPI's.

The DRPPC, located in France, allows the French subsystems experts to process and visualize housekeeping telemetry data. It communicates with SCC via Internet.

The Ground Station (GS), located in Natal/Brazil, constitute the direct interface with the Satellite and with the SCC providing telemetry, telecommand and tracking services for both the platform and the payloads. INPE's TT&C GS, located in Alcantara, will support the FBM during the LEOP phase.

The FBMBDS comprises a subset of the mission operations data. This data base will be populated and updated during the satellite AIT, it contains data of the space segment domain as well as parameters to control and monitor the GS. The same data base will also be used to generate the on-board software under responsibility of the Flight Software Producer Center (FSPC) and to control and monitor the satellite by the Ground Systems Operation team during the in-flight operation phases. To manage the satellite information by Brazilian and French teams, there will be a master copy at INPE and a slave copy at CNES of the FBMBDS.

The Data Communication Network (NET) provides the necessary framework for data communications among all the ground segment locations. It will use the existing network facilities at INPE and CNES and the Internet, between both countries.

The communication interfaces among the Ground Systems and those between the Ground Segment and the external entities are summarized in Figure 2.

The external entities took into account in the FBM Ground Segment are: the Brazilian and French Principal Investigators, the Satellite, the Brazilian and French expert teams (BSSE and FSSE), the Brazilian Payload Computer Team (BPCT) and the Flight Software Production Center (FSPC).

The FSPC is responsible to transmit the software and its related on-board table whenever a new platform software version is generated, indicating that SCC must loaded them to the satellite .

The BPCT is in charge of the Brazilian payload on-board computer (BPC) software. It shall send to the SCC new versions of the BPC software to be loaded to the satellite.

The ground segment makes the necessary satellite platform data available to the BSSE and to the FSSE allowing the respective teams to analyze the behavior of their subsystems.

The Brazilian and French PI´s (users), responsible for the payloads, communicate with the ground segment by sending Payload Work Plans and receiving both the payload telemetry and additional data, so the users can prepare operation plans and process the payload data to their experiments.

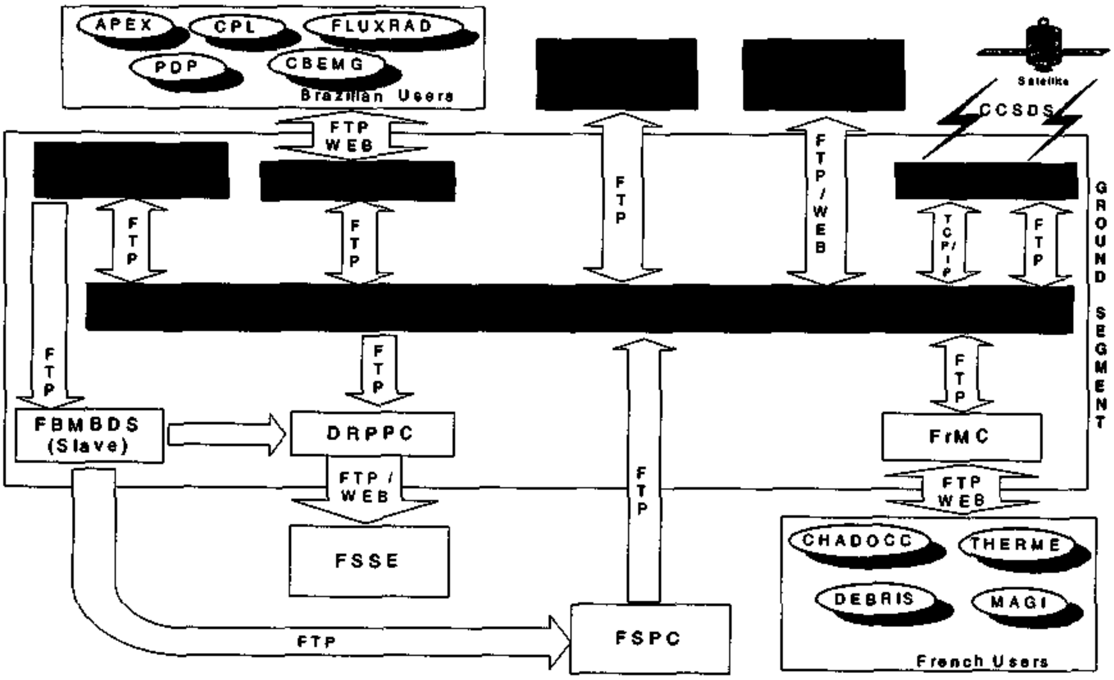

Figure 2 – Ground Segment Communication Interfaces

The Ground Segment communicates with the satellite by uploading Platform and Payload Work Plans and downloading platform and payload telemetry data through the CCSDS protocol.

OPERATIONS CONCEPT

The operation of the FBM satellite is immersed in a broader concept of System Operations, developed at CNES for the micro-satellite MYRIADE program and takes into account the satellite autonomy and the payloads operation scenarios.

At nominal conditions, the satellite is autonomous to carry out an operation plan for 11 days, that doesn't include the attitude control and the time synchronization what depends on ground commands once a day. For the payload nominal operation plan, the autonomy is of 8 days, limited only by the onboard buffers. At the end of the autonomy period, the satellite enters the SAFE Mode until a new work plan is received from ground.

Considering the satellite power budget, four different operational sequential scenarios for the payloads were foreseen within a 30 days period. The 30 days period will be repeated sequentially as well.

For the FBM Mission Operations, the *work plans* are uploaded once a week to the satellite. A *work plan* is defined as a set of time-tagged TCs directed either to the platform or Payload subsystems, through the onboard computer's software or the payload computer's software. For the payload, these *work plans* comprise a 8 days period called *programming period.*

Based on the *Programming Period,* the PI´s are responsible to prepare the work plans for their payloads respecting the pre-established operational scenarios. These plans are uploaded to the satellite once a week, on Thursday, in order to start their execution on Friday. The PI´s have a period of 4 days (Friday to Monday before the planned upload) to prepare their requests. The MC has a period of 2 days to get the users requests, to prepare the Payload Work Plans and to make these plans available to the FBM Satellite Control Center (SCC), to be retrieve via FTP. The PI's can access the following information to prepare the Work plans: orbit events, predicted orbit and pass plan. In the same way, the SCC prepares *Work Plans* for the satellite platform and for the Ground Station, as shown in Figure 3. The satellite executes the On-board Work Plans (platform and payloads) and records on-board the housekeeping telemetry which is down-linked at each visibility and analyzed by the SCC for S/C health analysis reporting. In case of any anomaly, or the spacecraft transition to the SAFE Mode, the SCC may interrupt all work plans and send immediate execution commands according to the Contingency Procedures.

During the Satellite passes the Payload and On-board Recorded Housekeeping Telemetry are stored in the GS. After each pass those data are transferred to the SCC.

The payload and the auxiliary data files, which are necessary to process the payload data, are delivered to the PI's via FTP at most 2 days after the data reception from the satellite. The auxiliary data comprises pre-defined housekeeping telemetry parameters, determined orbit and satellite attitude.

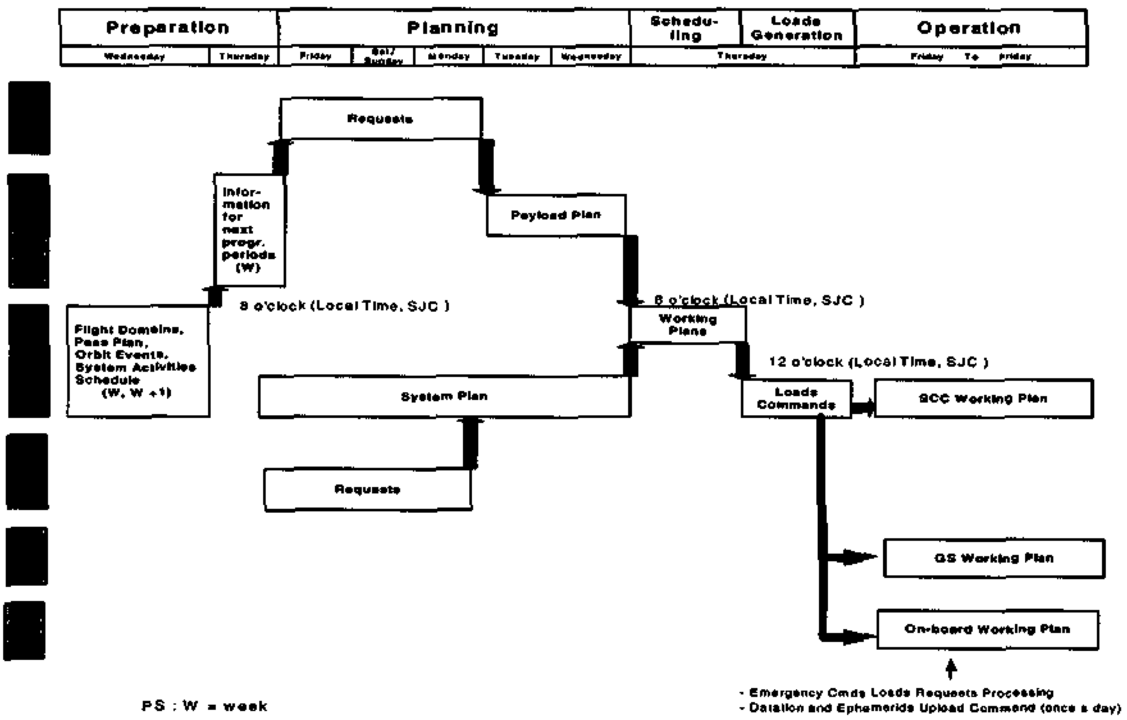

Figure 3: System Operations Programming Schedule

THE DEVELOPMENT PROCESS

Regarding the development process of the ground elements, namely SCC and MC, risk reduction in cost and schedule control, and user satisfaction, drove the adoption of the development model established by a well established European ECSS standards for space projects[1]. In fact, those standards define the phases, reviews and documentation of the development process and set a framework which enables the management and engineering teams to keep track of their progress and keep pace with the overall project schedule, budget and technical objectives. Tailoring and customization on the standards were necessary as the development progressed, mainly in the software development and the verification and validation (V&V) processes under INPE´s responsibility.

The ground segment project comprises the following five main activities: 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[2].

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 smaller subsystems, then each subsystem, hardware and/or software, has project, production, integration and test activities as well.

When the ground systems will be 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 ends the activities of the Ground Segment development. At this moment, all ground systems are supposed to be ready to the satellite operation.

Cost reduction, higher assurance and schedule conformance objectives drove the re-use of already developed and proven software elements. Indeed, most systems and sub-systems of the Ground Segment were inherited from previous projects, such as CBERS (China-Brazil Earth Resources Satellite), SACI (Scientific Applications Satellite), and Proteus (French Multi-mission Platform).

The same concept applies to EGSE, where, during AIT phase the satellite will be commanded by a replica of the SCC TM/TC module, named G1 – inherited from MYRIADE and PROTEUS projects, and the Base-Band equipment of the Ground Station.

In fact, the definitions of the *Ground Segment Internal Interfaces* (between SCC, MC and GS) and the *Satellite Model Data-Base*, which gathers all system information and is used by the SCC, AIT, on-board S/W, and Satellite Simulator development teams, were adopted for FBM, with minor changes, so that both programs, French and Brazilian, could benefit from already developed and tested modules for their ground sub-systems.

Regarding operations development activities, a main concern was to join users, SCC and operators together. Previous experience in SACI project dictated the need of exposing the users as soon as possible to their working environment. Meetings, questionnaires, sample screen shots and simulations are being used as tools to understand theirs needs and expectations, and avoid future problems for both sides, users and developers.

Concerning operations preparation activities, people from Operations team were invited as well to join the development effort, chiefly in the Training Simulator (specification, design and implementation) and in preparing the Operations Plans.

Extensive use has being made of in-house developed or COTS software tools in support of development and verification. Requirements management used Rational's RequisitePRO©, while the Simulator development will use ACESYMM© from Braxton.

VERIFICATION AND VALIDATION CONTROL AT SYSTEM LEVEL

By verification and validation at system level we mean the three phases: (i)Operational Validation, (ii)Technical Validation including all components of the ground segment and its integration with the space segment and (iii) the Ground Segment Integration.

Test Planing

The mission requirements, which are entries for the three phases of verification and validation planning, were specified in different documents namely Command and Control, Ground-Satellite Interface, TM&TC Plan, FBM System Specification.

In a cooperative way of work between CNES and INPE, these system requirement specification of the FBM mission were prepared by different teams, leading to duplication of requirements, from the point of view of the system tester team. In order to provide a systematic traceability of all requirements at each verification phase, identify testable requirement, eliminate redundancy and organize the System Test Matrix a *System Verification Database*, and related query and access tools were created in MS ACCESS©.

The relational logical schema of the this data base describes the relationship among the following entities: *requirement*, the *document* to which the requirement belong, the *test cases* for each requirement, the *test procedure*, *test environment*, the *test tools*, *test type* and *test results*, which will indicate the history of the test execution, e.g., if each test case has passed, failed or if it was inconclusive, whether it there was regression test and how many times it was done.

The solution has provided a low cost, easy-to-use, data base tool allowing rapid building and filling-in of verification matrices. Moreover, it will be a useful test planning and monitoring tool and will allow statistics during and after the test execution. Several reports can be generated crossing the populated information given by the data base. The most important are:

- list crossing requirement and test case, allowing to prove what requirement will not be tested (if there are any);

- list of all requirements tested by a given test tool;
- what test cases are the operational, the technical and the ground segment integration type.

Testing Tools

The set of tools to be used to apply the tests of Ground Segment Integration, System Technical Validation and Operation Validation phases are the following: Test Suitcase; Satellite Simulator; and System and AOCS Validation Bench (BVSS). All of them substitute the satellite in some functions.

Because of the great distance among the cities in Brazil, a tool like the Test Suitcase comprising the radio-frequency characteristics of the satellite is quite important. It will be used to execute mainly the GS - Satellite compatibility tests at radio-frequency level. Additionally, it will include the FPGA TMTC board, which implements the board/ground CCSDS communication protocol, so it will be used for the interface tests, at data handling level, between SCC and GS, SCC and Satellite; and the Technical Validation as well.

The BVSS, developed at CNES for the micro-satellite MYRIADE program, will be properly configured for FBM System and used for operability tests (covering routine and anomalies procedures) allowing to execute tests of on-board functional chains (central flight software, AOCS modes, etc..). Although this tool will not be a component of the Technical and Operational Validation environments on the FBM System Tests, it represents a quite important tool to pre-validate and debug operational procedures before the Operational Validation Phase and during the in-flight satellite Operational Phase. The operational procedures will be validated at CNES, during and after the pre-integration phase, as this tool is not available at INPE.

During the in-flight operation phase, the BVSS will be used, under CNES responsibility, to both, validate new on-board software version and test any new necessary procedures, which would not be possible to validate with the FBM Satellite Simulator.

The Satellite Simulator, is a software tool that will be used only for operators training and for test executions during the Operational Validation phase. It is a low-fidelity simulator providing only the most important aspects of nominal and contingency situations. It is supposed to be used neither for satellite fault analysis/diagnosis nor for new operational procedures evaluation. It will provide: TC acceptance and TM replayed accordingly, orbit and attitude simulation affecting the thermal behavior and the charge/discharge of the power system, the capability of simulating faulty satellite behavior. It will perform all nominal satellite operating modes, generate some payload telemetry as well as to log all simulation sessions.

CONCLUSIONS

The conception and development of the FBM Ground Segment and Operations Concept, in cooperation with CNES, may be considered of paramount importance in that new experience and skills were acquired by INPE Ground Systems Division and all FBM Engineering Team, as shown in the last table, below.

In the Ground Segment development, new processes supported by tools have been established taking into account the culture of INPE´s team. One of the main benefits was the suitable tailoring of a development process for ground systems to be reused in future projects.

Table 2: Acquired Skills and Experience

Driver	Needs	Acquired Skills / Experience
Multi-mission	On-board & Ground Autonomy	• S/W Development Tools • ECSS Standards • Simulation Tools • Requirements Engineering
Low-Risk	• Extensive Verification • Re-use of existing systems • Simulators	
Low-Cost	Reduce resources (1 Gr.Station)	
User-friendly	Simulators	

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