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Assembly, Integration and Test (AIT) Campaign of the Amazonia-1 satellite

Gabriel G. Coronel M[a]*, Felipe L. Marques[b], Guilherme Venticinque[c], Geilson Loureiro[d]

National Institute for Space Research (INPE), Av. dos Astronautas, 1758, São José dos Campos, Brazil, 12227-772

[a] gabrielg.coronelm@gmail.com - [b] flmfelipe72@gmail.com - [c] gui25@lit.inpe.br - [d] geilson@lit.inpe.br

* Corresponding Author

Abstract

This paper presents the process and activities of the Assembly, Integration and Test (AIT) campaign of the Amazonia-1 satellite. Amazonia-1 is the first Earth Observation satellite based on the Multi-Mission Platform (MMP) to be completely developed by Brazil. Including the development in the national industry of several pieces of equipment and parts, such as the structure, solar panels, harness, propulsion, and its payload, the Amazonia-1 will validate the MMP as a system, generating significant reductions in schedules and costs for the development of future satellite missions based on the MMP. The development of the Amazonia-1 satellite included several models (i.e. structural, thermal, electrical, and flight models), and specifically, the AIT campaign for the flight model was divided into 8 phases, each one related to a predefined system assembly state and a specific set of tests and activities. The maturity of the project and system increased in every step of the AIT campaign as tests demonstrated the compliance of requirements and allowed the identification of open points and nonconformances that needed to be solved before advancing to subsequent phases.

Keywords: assembly, integration, testing, systems engineering, satellite, verification

Acronyms/Abbreviations

Advanced WFI Data Transmission subsystem (AWDT), Assembly, Integration and Test (AIT), Attitude and Orbit Control Subsystem (AOCS), Attitude Control Electronics (ACE), Battery Simulator (BTS), Break-out-Boxes (BOBs), Business Process Model and Notation (BPMN), Contrast Transfer Function (CTF), Digital Data Recorder subsystem (DDR), Electrical Model (EM), Electrically Erasable Programmable Read-Only Memory (EEPROM), Electromagnetic Compatibility (EMC), European Cooperation for Space Standardization (ECSS), Error Vector Magnitude (EVM), Fault Detection, Isolation, and Recovery (FDIR), Flight Model (FM), Global Positioning System (GPS), Ground Support Equipment (GSE), Launch and Early Orbit Phase (LEOP), Mission Control Center (MCC), Multi-Layer Insulation (MLI), Multi-Mission Platform (MMP), National Institute for Space Research (INPE), Near Infra-red (NIR), On-Board Computer (OBC), On-Board Data Handling (OBDH), Payload Module (PM), Polar Satellite Launch Vehicle (PSLV), Power and Control Distribution Unit (PCDU), Power Supply Subsystem (PSS), Radio Frequency (RF), Random Access Memory (RAM), Remote Sensing Data Center (RSDC), São José dos Campos (SJC), Satellite Emergency Mode (SEM), Satellite Launch Mode (SLM), Satellite Routine Mode (SRM), Satish Dhawan Space Centre (SHAR), Service Module (SM), Solar Array Drive Assemblies (SADAs), Solar Array Generators (SAGs), solar array simulator (SAS), Specific Check-Out Equipment (SCOE), Telecommand (TC), Telemetry (TM), Telemetry and Telecommand (TM&TC), Telemetry and Telecommand Subsystem (TT&C), Thermal Balance Test (TBT), Thermal Control Subsystem (TCS), Thermal Cycling Test (TCT), Tubo de Calor (TUCA), Thermal-vacuum tests (TVT), Visible (VIS), Wide Field Imager subsystem (WFI).

1. Introduction

Brazil has different biomes, a diversified agricultural system, and complex hydrological, energy, geological and topographical systems. There is a permanent need to monitor all these targets. Additionally, there is a need to monitor one of the main environmental problems in Brazil, which is deforestation, especially in the Amazon rainforest.

The Amazonia-1 mission was defined to meet these needs.

1.1 Amazonia-1 mission

The main objectives of the Amazonia-1 mission are to allow the deforestation evaluation and identification and to allow a high-rate agricultural and vegetation analysis. In addition to these objectives, the Amazonia-1 mission is expected to be useful for other applications, such as monitoring of coastal zones, inland reservoirs, natural and cultivated forests, and disasters.[1]

1.2 Space system

In order to meet the aforementioned objectives, the Amazonia-1 space system will produce image data of Brazil with a spatial resolution better than 70 m in four spectral bands with a revisit time of 5 days and image availability of at most 1 day after image acquisition. The system will be capable of taking images of any part of the globe and producing processed images from levels 1 to 4.

The space system is divided into four segments: application, control, launch, and space segments.

The application segment consists of two ground stations and the Remote Sensing Data Center (RSDC). The main ground station for receiving image data in X-band is located in Cuiabá while the backup ground station is located in Cachoeira Paulista. The RSDC, which is responsible for recording, archiving, processing, and distributing data to users, is also located in Cachoeira Paulista. The application segment interfaces with the control segment in order to receive satellite information and to request any payload operation as required.

The control segment consists of four ground stations and the Mission Control Center (MCC). The main ground station for receiving telemetry and telecommand (TM&TC) communication in S-band is located in Cuiabá while the backup ground station is located in Alcântara. The MCC is located in São José dos Campos and it is responsible for the operation of the satellite, the flight plan, the telemetry (TM) processing, and the telecommand (TC) sending.

The launch segment consists of the Polar Satellite Launch Vehicle (PSLV) and a separation ground station. The PSLV is a four-stage launch vehicle[2] responsible for carrying the Amazonia-1 satellite near to its nominal orbit from the Satish Dhawan Space Centre (SHAR) in India.

Finally, the space segment consists of the Amazonia-1 satellite. The following section provides further details on the satellite.

Fig. 1 provides a simplified view of the Amazonia-1 space system during nominal operation.

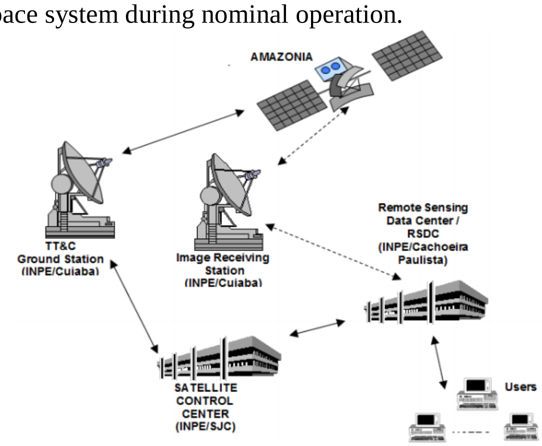

Fig. 1. Amazonia-1 space system.[1]

1.3 Amazonia-1 Satellite

Table 1 provides a summary of the main features of the Amazonia-1 satellite.

Table 1. Main features of the Amazonia-1 satellite.[3-5]

Spacecraft size	≈ 2.6 x 1.75 x 0.95 m
Spacecraft Launch Mass	≈ 638 kg
Spacecraft Dry Mass	≈ 593 kg
Spacecraft design life	4 years
Orbit type	Sun-Synchronous Orbit
Orbit altitude and period	752 km; 100 min
Spatial resolution	<70 m
Swath	≈ 850 km
Revisit time	5 days
Power Consumption	≈ 415 W (peak)
TM&TC band	S-band
Image downlink band	X-band
Image bands	0.45 - 0.52 μm (VIS), 0.52 - 0.59 μm (VIS), 0.63 - 0.69 μm (VIS), 0.77 - 0.89 μm (NIR)

Amazonia-1 satellite is divided into two modules: the service module (SM) and the payload module (PM). Satellite configuration consists of the PM coupled over the SM (see Fig. 2). The PM gathers all the equipment needed to meet mission objectives. On the other hand, SM gathers all the equipment needed to support the payload module operations.[3]

Fig. 2. Amazonia-1 satellite.[3]

1.3.1 Service module

The SM of the Amazonia-1 satellite is based on the Multi-Mission Platform (MMP), which is a generic platform developed to gather all the equipment needed to be used on several space missions. Conceived to meet a comprehensive range of pointing, power, thermal control, communications, and data handling requirements, the MPP is able to support several mission concepts and different payloads.[6]

The Amazonia-1 satellite will validate in orbit the MMP and, once validated, the MMP will bring benefits to Brazilian space projects, such as cost reduction, shorter development schedules, and maturity to future missions.[6]

1.3.2 Payload module

The PM of the Amazonia-1 satellite is composed of the Wide Field Imager (WFI), the Digital Data

Recorder (DDR), and the Advanced WFI Data Transmission (AWDT) subsystems. The PM module also carries an aluminum acetone-charged heat pipe called TUCA (an acronym for "Tubo de Calor", in Portuguese) for qualification and certification in orbit.

2. Verification approach

This section provides a summary of the verification approach of the Amazonia-1 project. This paper focuses on the verification activities performed specifically for satellite AIT. Other verification activities performed before AIT operations at subsystem or lower levels are not included.

2.1 Methods

Amazonia-1 satellite verification methods were in conformance with European Cooperation for Space Standardization (ECSS) verification standard[7]. Consequently, review-of-designs, analyses, inspections, and tests were performed during the whole Amazonia-1 project. However, tests represented the relevant part of the AIT campaign so this paper focuses mainly on them.

Satellite tests were divided into three categories: system tests, system checks, and subsystem tests. System tests aimed to verify that the satellite, as a system, operated properly in all operational modes and conditions, including redundant, degraded, and transient modes. System checks, a subset of the system tests, were performed before, during, and after environmental tests, as required. Finally, the subsystem tests aimed to verify all subsystems' functionality and performance that was possible to be verified with such subsystems assembled and integrated into the satellite.

2.2 Verification stages and model philosophy

An electrical model (EM) was developed for the electrical design verification including functional, performance, and auto compatibility tests prior to the flight model (FM) development. The EM also validated the AIT process (e.g. procedures, test setups, and staff) and the Ground Support Equipment (GSE). Furthermore, the EM validated the use of Business Process Model and Notation (BPMN) to conduct electrical tests[8].

This electrical model was used for electromagnetic compatibility (EMC) tests to verify that the satellite was able to function properly without introducing or being susceptible to external disturbances and that the pieces of equipment of the satellite were not affecting each other.

Then, the FM was used for acceptance tests. The following section describes the AIT campaign of this model.

Other models previously developed in the Amazonia-1 project were the radiofrequency (RF) mock-up, the structural model, and the thermal model. However, they are not within the scope of this article.

3. Amazonia-1 FM AIT campaign

The AIT campaign aims to integrate and demonstrate that the satellite is ready for launch and to perform its mission in the space environment.

The whole AIT campaign of the Amazonia-1 satellite is divided into eight phases (not including the preparation phase or phase 0) in which the satellite is progressively integrated while demonstrating its performance.

Phases 1 to 4 relate mostly to the progressive assembly and system integration.

Phases 5 and 6 relate to environmental tests while phase 7 relates to the final functional tests and the preparation for phase 8, in which the satellite will be launched.

Throughout the phases, the satellite and the GSE formed specific groupings that were called system assembly states.

The following sections provide more details about system assembly states and phases.

3.1 System assembly states

System assembly states follow a sequential and gradual evolution of the satellite and the GSE during the AIT life-cycle, in which the satellite starts with its simplest and more accessible configuration in the state A and it progresses to subsequent states until it gets the closest to the flight configuration in the state D2.

State D3 is a variation case used for thermal-vacuum tests (TVT).

The following sections describe the seven states defined for the Amazonia-1 FM campaign.

3.1.1 State A

In this state, both modules' structures are at their simplest and more accessible form. For the SM, the structure is delivered with the propulsion tank and pipelines already assembled, i.e. propulsion assembly. Both modules are separated, without equipment, and with their lateral panels all open. This state was used during phase 1.

As mentioned, state A is the most accessible state for electrical interface verification and mechanical assembling. Consequently, state A characterizes by the use of savers connectors prior to the final electrical connection and typically the use of Break-out-Boxes (BOBs) for interface verification and inspection.

3.1.2 State B

State B characterizes by both modules still separated but the equipment assembled on the structure (see Fig. 3). This state was built during phase 1 and used during phase 2 for subsystem tests.

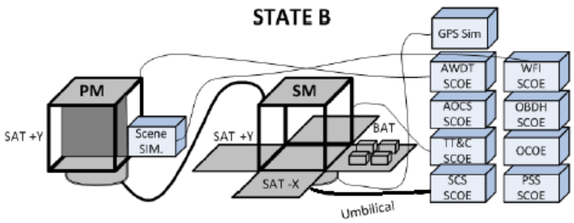

Fig. 3. Amazonia-1 system assembly state B.

3.1.3 State C1

In this state, the PM is assembled over the SM. The structure lateral panels remain open, so additional cage frame locking devices are required so the structure can withstand PM weight without structural risks. In this state, satellite's antennas are not still assembled, so RF communication and tests need to be performed by cables connected from the RF Specific Check-Out Equipment (SCOE) to the antennas' ports (see Fig. 4). This state was used in phase 3.

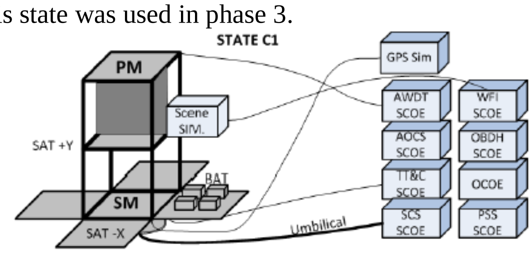

Fig. 4. Amazonia-1 system assembly state C1.

3.1.4 State C2

Amazonia-1 has five antennas: two for TM&TC signals reception and transmission, two for Global Positioning System (GPS) signals reception, and one for payload data transmission. State C2 represents an evolution of the state C1 with the assembling and integration of the antennas. At this state, RF communication and tests need to be performed by wireless links between the satellite and the RF SCOE. This state was used in phase 3.

3.1.5 State D1

This state represents an evolution of the state C2 with the final layout of the harness and the closure of structure lateral panels. In this state, the satellite is completely closed. This state was used in phase 4.

3.1.6 State D2

This state represents an evolution of the state D1 with the assembly and integration of the Solar Array Generators (SAGs). This state represents the satellite final flight configuration (see Fig. 5). During phase 5, the satellite lacked the Multi-Layer Insulation (MLI) and it had a set of accelerometers that will not be installed for launch. During phase 7, the satellite will be at this state for final functional tests but then, the SM and the PM will be undocked to be transported to the launch base. Finally, the satellite will be again in this state in phase 8 at the launch base when it will be ready for launch.

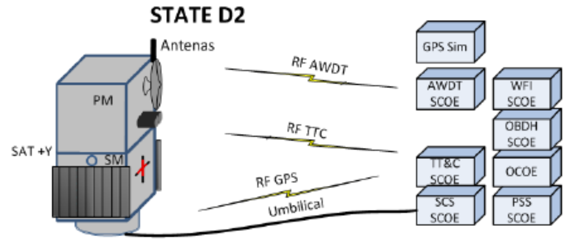

Fig. 5. Amazonia-1 system assembly state D2.

3.1.7 State D3

This state is an adaptation of state D2 for TVT. This state was used in phase 6. Solar panels and accelerometers used for vibration tests were removed, antennas were electrically disconnected but kept assembled on the satellite, and finally, MLI, thermocouples, and external heaters were installed on the satellite.

3.2 AIT Phases

Phases were sequentially ordered, starting from the hardware delivery and preparation at phase 0 until the launch campaign at phase 8. Depending on the system assembly state, the evolution of the integration, and based on the system and subsystem test specifications, a test applicability matrix was elaborated describing the specific set of tests to be performed within each phase. The selection of applicable tests within each phase required some trade-offs among risks, feasibility, and conflicting requirements between system and subsystem test specifications.

Fig. 6 illustrates the Amazonia-1 FM AIT sequence.

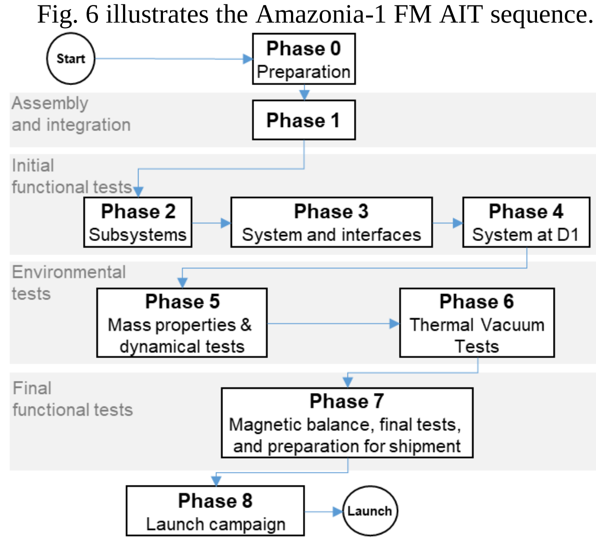

Fig. 6. Amazonia-1 FM AIT sequence.

3.2.1 Phase 0

This phase can be regarded as a preparation or pre-AIT phase since it included the acceptance of the equipment by the AIT team and the preparation of the satellite and the GSE for subsequent assembly and integration activities. At the end of this phase, the structure, the propulsion assembly with its thrusters, and the reaction wheels were assembled and aligned.

Acceptance of equipment was performed by incoming inspections performed to all parts and equipment delivered to the AIT team. Incoming inspections included visual, mechanical, and electrical inspections of the delivered parts and equipment.

Preparations for AIT included the assembly and alignment adjustments of the propulsion assembly and the reaction wheels. It also included a local leakage test.

Alignment measurements and adjustments were performed to ensure that critical equipment was aligned within the specified tolerances with respect to the reference coordinated system. Equipment with alignment requirements were the payload as well as sensors and actuators of the Attitude and Orbit Control Subsystem (AOCS), i.e. thrusters, gyroscopes, reaction wheels, and star sensors. Alignment measurements and adjustments included the assembly of master and auxiliary cubes and the validation of test equipment. Due to the design of the satellite, in which most pieces of equipment were assembled over the lateral panels and lateral panels remained open for some states, only thrusters' and reaction wheels' alignment adjustments were performed during this phase.

The leakage test was performed to demonstrate that the propulsion subsystem kept its structural integrity under the maximum operating pressures for a duration sufficient to establish that the leak rates were within the specified limits.

Preparation of the GSE was performed to demonstrate that it was ready for use and that its use was not risky to the satellite.

3.2.2 Phase 1

This phase can be regarded as the assembly and integration phase. Starting in state A, this phase ended with the satellite with most of its equipment already assembled and integrated. Coarse sun sensors and star sensors were also assembled and integrated at the beginning of phase 2, antennas were assembled and integrated during phase 3, and SAGs were assembled and integrated during phase 5.

During phase 1, mechanical activities included mounting the structure frames and parts as well as the equipment and harness into the satellite structure. The assembly of internal MLIs, heaters, thermal coatings, and thermal inter-fillers was also performed. Finally, torque and resin were applied to all bolt connections.

Electrical activities included bonding measurements verification after assembly of the pieces of equipment, verification of the interfaces between the SCOE and the satellite (e.g. umbilical, RF, and skin connectors), and verification of the equipment's power and signal interfaces.

Bonding measurements were performed during the assembly of all equipment on the satellite's structure to ensure that the structures of the equipment were in electrical contact with the satellite structure and that grounding resistances were lower than a specified limit, so the satellite had a single point ground within the power subsystem.

The verification of interfaces was performed to ensure that units could be safely connected to the others as well as SCOE to the satellite. This verification followed a typical integration sequence[9]. Power and Control Distribution Unit (PCDU) input interfaces were verified first. Then, the output power interfaces between PCDU and the On-Board Computer (OBC) were verified. Next, interfaces between PCDU, OBC, and Telemetry and Telecommand Subsystem (TT&C) were verified. Once the power and basic signal interfaces of these subsystems were integrated, the integration of other equipment was able to be performed, always starting from the power interfaces and then the basic signal interfaces. At the end of phase 1, as a result of the sequential process, the equipment was assembled, the basic interfaces were integrated, and the whole set of SCOE was already connected to the satellite.

3.2.3 Phase 2

This phase was characterized by the subsystem tests. During this phase, the satellite was in state B with most of its equipment already assembled and with the basic interfaces verified, allowing the final integration and tests of the subsystems. Electrical tests were performed focused on subsystems' functional and performance verification.

Once mechanical activities (e.g. partial arrangement of harness and RF cables, WFI scene simulator installation, locking of screws and connectors, and propulsion tank pressurization) were performed, subsystem tests were carried on. Coarse sun sensors and star sensors were assembled and integrated at the beginning of this phase.

Subsystem tests were performed to demonstrate the compliance of the subsystem in terms of functions, performance, and interfaces after integration to the satellite. Tests in this phase were related to all satellite subsystems, i.e. Power Supply Subsystem (PSS), On-Board Data Handling (OBDH), AOCS, TT&C, WFI, AWDT, DDR, and Thermal Control Subsystem (TCS).

PSS integration and tests verified the PCDU/SCOE interfaces and the proper functioning and performance of PCDU in terms of battery management (i.e. charge control currents and voltages), battery worst-load conditions at different bus voltages and subsequent Fault Detection, Isolation, and Recovery (FDIR) actions, pyrotechnic circuit activation in normal and non-normal conditions at different bus voltages, and equipment in-rush currents at different bus voltages. Solar Array Drive Assemblies' (SADAs) channels were also verified passing power through their slip rings while in motion. PSS tests also verified power and signal interfaces with other equipment as well as operational modes of PSS subsystem and TM&TC. Some of these tests required the use of a battery simulator (BTS) and a solar array simulator (SAS).

AOCS integration and tests consisted mainly of the verification of Attitude Control Electronics (ACE) interfaces with peripheral equipment, i.e. magnetometers, reaction wheels, GPS, magnetorquers, thrusters, SADAs, solar sensors, and star trackers. ACE/SCOE interfaces and the capacity of uploading software versions into ACE through them were also verified during phase 2. AOCS tests also included the functional verification of latching, upstream, and downstream valves activation as well as thrusters activation. AOCS tests also verified power and signal interfaces with other equipment as well as TM&TC.

OBDH integration and tests included verification of GPS configuration and management functions (e.g. determination of position, velocity, and time), configuration and data monitoring of the Random Access Memory (RAM) and the Electrically Erasable Programmable Read-Only Memory (EEPROM), and verification of some basic OBC FDIR actions. During this phase, only standard FDIR actions were verified.

TT&C integration and tests included the verification of non-coherent mode frequency stability, output frequency and power measurements, receiver rest frequency, carrier acquisition and tracking, carrier acquisition threshold, spurious emissions, command sensitivity threshold, telemetry and telecommand interfaces, power and interfaces with other equipment, and operational modes of the transponder (i.e. coherent and non-coherent modes) at different telemetry rates.

WFI integration and tests included Contrast Transfer Function (CTF), relative gain factors, integration time, radiometric resolution, data format/scrambling, internal radiometric calibration, telemetry and telecommand interfaces, operational modes, and power and signal interfaces with other equipment.

AWDT integration and tests included output power and frequency measurements, harmonics and spurious emissions, modulated output spectrum, Error Vector Magnitude (EVM), telemetry and telecommand interfaces, operational modes, and power and signal interfaces with other equipment

DDR integration and tests included the verification of the proper real-time imaging data passing through the DDR subsystem, data recording, playback and erasing capabilities, DDR self-test function, telemetry and telecommand interfaces, and power and signal interfaces with other equipment.

TCS integration and tests included the verification of the electrical connection between the OBC and the thermistors, the electrical connection between the PCDU and the heater circuits, the accuracy of the thermistors, heater control algorithms, telemetry and telecommand interfaces, and power and signal interfaces with other equipment.

3.2.4 Phase 3

This phase can be regarded as the system tests phase. During phase 3, both system and subsystem tests were performed after the PM was assembled over the SM. However, the focus during this phase was on system tests. In the first part of this phase, the satellite was in state C1. In the second part, the state was changed to state C2 to verify RF links using antennas.

Mechanical activities at the beginning of this phase included activities such as the final arrangement of PM's harness and RF cables, WFI scene simulator removal and installation, locking of screws and connectors, thermocouples installation in the PM, docking of the PM over the SM, and propulsion tank pressurization. Later in the phase, mechanical activities were performed to change the satellite from state C1 to C2, including the assembly and integration of TT&C's, GPS's, and AWDT's antennas and AWDT's waveguides as well as the removal and installation of the scene simulator to allow those operations.

Subsystem tests during this phase verified the compliance of the subsystems in terms of functions, performance, and interfaces that were not possible to verify during the phase 2 in which the satellite was at state B. These tests also ensured that the docking operation of the modules was performed properly without any damage or improper connection. Tests in this phase included AOCS, TT&C, AWDT, GPS, DDR, TCS, and WFI tests. AOCS tests during this phase consisted of closed-loop tests used to verify the pointing capacities of the satellite under different conditions. TT&C and AWDT tests during this phase were performed both through coaxial cables at state C1 and through wireless links using antennas at state C2. GPS tests were performed only at state C2 to verify the correct reception of data through antennas.

System tests during this phase demonstrated the compliance of the system-level functions, performance, and interfaces. System tests were divided into Satellite Launch Mode (SLM), Satellite Emergency Mode (SEM), Satellite Routine Mode (SRM), and segment interfaces tests.

SLM tests were executed to demonstrate compliance with satellite requirements during the Launch and Early Orbit Phase (LEOP). SLM tests included nominal initial sequence operations and worst conditions simulations.

SEM tests were performed to demonstrate compliance with satellite requirements during emergency operations. SEM tests included the verification of FDIR actions, such as automatic switching to redundant units and operational modes transitions.

SRM tests were performed to demonstrate compliance with satellite requirements during routine operations. SRM tests included nominal imaging operations (image data acquisition, recording, and playback transmission), imaging operations in redundancy circuits, and an endurance test. The endurance test consisted of 100 hours with the satellite operating at the routine mode in order to demonstrate the system's robustness.

Segment interfaces tests included application segment compatibility tests and control segment compatibility tests.

Application segment compatibility tests validated the interfaces between the satellite and the application segment. They mainly consisted of receiving the image data generated by the satellite and delivering it to a computer with the application segment's software. Then, the analysis of the received image and the related auxiliary data was performed to confirm that the interfaces were correctly implemented.

Control segment compatibility tests validated the interfaces between the satellite and the control segment. These tests validated the correctness of the operations control and monitoring software as well as some procedural contents of the flight operations plan.

SRM, TT&C, and AWDT tests were performed in both states, C1 and C2. Endurance, WFI, DDR, and GPS tests were only performed at state C2. The rest of the tests of this phase were performed at state C1.

3.2.5 Phase 4

At this phase, the satellite was tested in the state D1, in which it was fully assembled, except for MLI and SAGs. State D1 allowed the execution of some system tests that were not possible at previous states.

At the beginning of this phase, mechanical activities were performed to change the satellite state from C2 to D1. These activities included the final arrangement of harness and RF cables, locking of connectors with epoxy adhesive, installation of internal sensors for environmental tests (e.g. accelerometers and thermocouples), and closure of external lateral panels of both PM and SM.

The closure of some specific lateral panels enabled the execution of the alignment measurements of the star sensors and gyroscopes. The alignment of the camera was also performed at that moment.

After the satellite was in state D1, system tests were performed. Specifically, SRM tests were carried on as described in the previous section. Some subsystem tests (i.e. TT&C, AWDT, WFI, and TCS) were also carried on during this phase to ensure that lateral panels closure did not affect their functions and performance. For the TT&C subsystem, an additional test was performed during this phase to verify the polarization of the antennas. Some AOCS tests were also carried on since the new state of the satellite allowed their execution, such as gyroscopes interfaces with ACE and magnetic perturbation in the magnetometers.

Launch vehicle separation tests were also carried on during phase 4. Launch vehicle separation tests verified the proper compatibility between the satellite and the separation system, both in terms of electrical and mechanical interfaces. During the separation test, shock measurements were performed to assess the levels generated by the separation system activation and to ensure that such levels and the frequency spectra were within specified limits.

3.2.6 Phase 5

At the beginning of this phase, the satellite yet in state D1 passed through mass properties measurements. Then, SAGs were assembled, so the satellite changed to state D2 and it was subjected to dynamical tests, followed by system checks. At the latest part of the phase, SAGs were deployed by pyrotechnic devices. Then, both SAGs were disassembled, and finally, the satellite was subjected to system and some subsystem tests.

Mass properties measurements during this phase verified that the mass, center of gravity, and moment of inertia around the three axes of the satellite were within the specified limits.

SAGs assembly included several activities, such as inspections, mechanisms and pyrotechnic devices installation, manual deployments, and electrical functional verifications.

Other activities performed before dynamical tests included external accelerometers installation, propellant tank filling with Helium, local leakage test, and finally, partial tank depressurization.

Dynamical tests included both vibration and acoustic tests and they were performed to demonstrate that the satellite can withstand the vibration and acoustic environments that it will face during launch and that the satellite is sufficiently stiff to meet the axial and lateral frequency requirements of the launch vehicle.

Vibration tests included for each satellite axis a low-level random test, three-level sine-dwell tests for strain gage calibration, a low-level sine sweep for initial structure dynamic characterization (i.e. initial signature), a sine sweep test at acceptance level, and finally, a low-level sine sweep test for final signature. The results of both final and initial signatures are compared to identify possible modifications of the satellite structural status.

Acoustic tests included a low-level acoustic test for initial signature, an acoustic test at acceptance level, and finally, a low-level acoustic test for final signature. The results of both final and initial signatures are compared to identify possible modifications of the satellite structural status.

After vibration tests on each satellite axis and the acoustic tests, system checks were performed.

Once dynamical tests were finished and system checks demonstrated proper functioning of the satellite, SAGs deployment tests were performed. SAGs deployment tests demonstrated the correct functioning of the SAGs deployment mechanisms and proper deployment times. Since deployment tests were performed with real pyrotechnic devices, shock measurements were performed during deployments to measure the levels generated by the pyrotechnic devices activation and the SAGs release and latching and to ensure that the levels and the frequency spectra were within specified limits.

After SAGs removal, system tests were carried on. Specifically, SRM tests were carried on. TT&C, AWDT, WFI, and TCS tests were also carried on.

Alignment measurements were also performed during this phase to verify that the satellite withstood the dynamical environment and the alignment requirements were still being met. These measures were compared against the ones obtained in phases 0 and 4.

3.2.7 Phase 6

At the beginning of this phase, the satellite was changed to state D3 and moved to a vacuum chamber.

A system check was carried on before the closure of the vacuum chamber door to verify the test setup and interfaces, ensuring that all operations and tests specified were able to be performed during TVT.

Then, leakage and TVT tests were performed. TVT included Corona effect monitoring, Thermal Balance Test (TBT), and Thermal Cycling Test (TCT). Global leakage tests were performed before the beginning of the TBT and at the end of TCT tests. Contamination probes were also installed close to the satellite and analyzed after tests to determine any trace of contaminating material.

TVT were performed to verify the ability of the thermal control subsystem to maintain temperatures inside specified operational limits and the ability of the other subsystems to achieve their performance requirements under the vacuum and thermal conditions expected to be encountered during the mission. These tests served also to clean and decontaminate the satellite, and to demonstrate that no electrical arc occurred under realistic launch pressure conditions and that powered equipment during launch worked properly under such pressure circumstances.

System tests were carried on during TCT. Specifically, SRM tests were carried on. TT&C, AWDT, and WFI tests were also carried on.

3.2.8 Phase 7

Phase 7 had not been executed at the moment of writing this paper. However, it is expected that at the beginning of this phase, antennas will be reconnected and the satellite will pass through final system tests.

After final system tests, a magnetic balance test will be performed to determine the residual magnetic moment of the satellite and to demonstrate conformance to magnetic cleanliness requirements.

At the end of this phase, the satellite will be changed to state D2 to prepare it for shipment to the launch base. SAGs will be reassembled, integrated, and manually tested. Pyrotechnic devices will also be assembled but not connected. MLI will be partially installed. Finally, SM and PM will be undocked to be transported in different shipping containers. GSE will also be prepared and packed for shipment to the launch base.

3.2.9 Phase 8

Phase 8 comprises the satellite transportation to the launch base in India, preparation of the GSE and the satellite at the launch site, integration with the launch vehicle, and finally, the launch.

At the launch site, the docking of the PM over the SM will be performed. Then, a system check will be performed to ensure that the satellite is completely operational after transportation and docking operations.

Final MLI assembly and partial flight/no-flight items operation will be executed before the integration of the satellite with the separation system and launch vehicle’s interface. Then, a leakage test will be performed to the satellite to ensure that the propulsion subsystem did not suffer any damage from transportation so it is safe to be fueled. After fueling, the satellite will be moved to the launch pad.

At the launch pad, a reduced system check will be performed and then, the final set of flight and no-flight items will be installed and removed, respectively. Then, the fairing will be assembled and a final system check will be performed together with the full charge of the batteries. A launch countdown rehearsal will be performed and terminal countdown and launch will happen to end the AIT campaign of the Amazonia-1 satellite.

4. Conclusions

The Amazonia-1 AIT campaign was divided into 8 phases (excluding preparation phase), sequentially ordered, in which a specific set of activities and tests were defined according to system assembly states, evolution of the integration, and the system and subsystem test specifications.

The AIT of the Amazonia-1 satellite has had several challenges. However, the maturity of the project and the system increased in every step of the AIT campaign as tests demonstrated the compliance of requirements and allowed the identification of open points and nonconformances that needed to be solved before advancing to subsequent phases. In the meantime, the AIT campaign allowed the AIT team to gain invaluable experience.

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