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THERMAL-VACUUM TESTS OF THE AMAZONIA-1 SATELLITE TM PERFORMED AT INPE WITH SUCCESS

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Abstract

The Amazonia-1 is a spacecraft under design and construction by the National Institute for Space Research - INPE, in Sao Jose dos Campos, SP, Brazil, with some partners from the industry. With mass of approximately 500kg and carrying a wide-field imager as the main payload, this polar-orbit satellite has as its main mission the monitoring of the Amazon region.

For the proper qualification of the spacecraft design, a Thermal Model (TM) representing the proposed philosophy for the thermal conditioning of the satellite during its orbital flight was completely assembled at the Integration and Testing Laboratory - LIT, INPE. During November and December 2015 this test model was submitted to a comprehensive thermal-vacuum testing campaign, simulating several orbital conditions that this satellite will have to face and to successfully stand during its operational lifetime in space.

For this environmental test, the Amazonia-1 Thermal Model, containing dummy boxes representing its operating subsystems and equipment, holding the same thermal-optical properties as the flight model on its surfaces, was accurately prepared with the installation of more than 100 sets of skin-heaters that were then used to provide the expected heat load exchange at each significant section of the spacecraft, the internal heat dissipation of the on-board active subsystems, and also the heat dissipation from the spacecraft thermal control system. In order to obtain the detailed and continuous temperature data along the test, more than 250 temperature sensors, as type-T thermocouples and also thermistors, were installed on meaningful points of the spacecraft and taken to a dedicated data acquisition system. All the skin-heaters were properly electric diagram configured, their cables routed and adequately connected to a cluster of 100 power supplies that, programmed and controlled by computers, could provide the required heat dissipation levels along the test.

Loaded in the INPE-LIT 6m x 8m Space Simulation Chamber and suspended by stainless-steel cables aiming to get a better thermal insulation from the test set-up, the Amazonia-1 Thermal Model was submitted to a pre-defined sequence of hot and cold cycles with emergency states, where a Thermal Balance procedure was then executed in order to get the required data to be compared to the mathematical thermal modelling, and to fully validate the thermal design of the Amazonia-1 spacecraft. This paper presents details of this spacecraft thermal-vacuum testing campaign.

Keywords: Thermal-Vacuum Tests, Spacecraft Environmental Tests, Space Simulation

1. Introduction

For space programs that are based on spacecraft holding new design or conception, a full-size thermal model (TM) of the spacecraft is mandatory for the proper verification and qualification of its orbital or interplanetary cruising thermal behaviour. The Amazonia-1 satellite belongs to a Brazilian project dedicated to undertaking Earth observation operations in the country with some emphasis on the Amazon region, and the first steps of this program in terms of spacecraft qualification are being carried out at the Integration and Testing Laboratory, located in Sao Jose dos Campos, SP, Brazil. Following an elected philosophy, the structural model of the spacecraft was properly modified and adapted to be transformed into a full-size thermal model of the future satellite.

Inside a 10,000 Class Clean Room, from March to October 2015 this full-size spacecraft thermal model was modified, integrated and accordingly prepared for the subsequent thermal-vacuum testing campaign. Surface contact electrical resistances, commonly referred as *skin-heaters*, were used to provide the spacecraft internal heat dissipation, and temperature sensors were installed on many locations of the thermal model in order to monitor their temperature along the environmental test. The LIT-INPE largest space simulation chamber was then used to provide the correct space environment in terms of high vacuum and low temperature background, so the Amazonia-1 thermal model was able to be tested for qualification during several days, producing a significant amount of data that was then used by the thermal engineers on the analysis for the proper qualification of the spacecraft in terms of temperature and thermal control. It is relevant to mention that this particular thermal-vacuum test of a spacecraft was actually performed in two distinct periods of time in sequence, a procedure not so common in a test campaign of a spacecraft thermal model. The thermal-vacuum tests of the Amazonia-1 TM was considered as a complete success, and some details of this test campaign are presented hereafter.

2. **The Amazonia-1 Spacecraft**

Included in the Brazilian space program, the Amazonia-1 satellite is the first spacecraft (S/C) to use the proposed philosophy of adopting a generic platform able to carry distinct payloads to comply with some variant space missions of interest of this country. Particularly, the Amazonia-1 satellite carries a wide-field imager for remote sensing purposes, including the mission of monitoring the deforestation rate of the Amazon region.

Measuring approximately 1.4m x 1.8m x 2.5m and weighting approximately 500kg, the spacecraft has a designed polar orbit of 750km of altitude and lifetime of 4 years. An artistic image of the spacecraft can be seen in Figure 1.

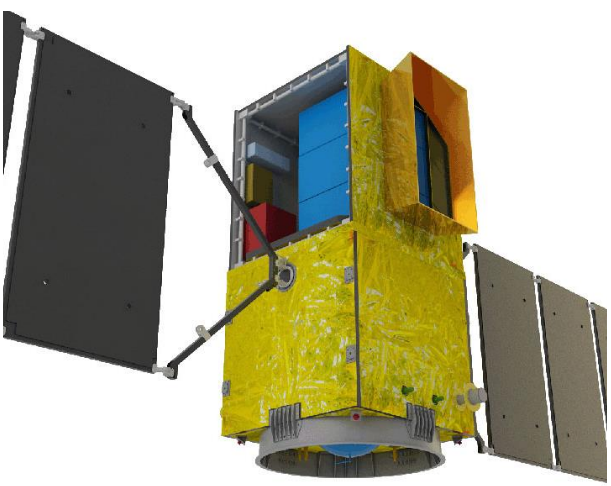

Fig. 1 - The Amazonia-1 Satellite

3. **The Amazonia-1 Thermal Model preparation**

Aiming to avoid unnecessary additional costs to the project, the thermal model of the Amazonia-1 spacecraft was actually derived from the structural model. Some parts that were considered as not relevant for thermal purposes were removed, and some items were included in the model to ensure its adequacy to represent the actual thermal behaviour of the spacecraft while in orbital flight.

As quite typical for S/C thermal models, the actual flight equipment electronics were replaced and represented by mechanical dummies, in this case as metallic boxes, where electrical heaters (skin-heaters) were installed in order to produce the desired thermal dissipation as the original equipment will do along their expected operational condition in orbit.

Fig. 2 - The actual Amazonia-1 Thermal Model

In total, a significant amount of skin-heaters was installed in the thermal model and, wherever possible and following some criteria of optimization of the electrical circuit, some heaters were wired in parallel or even in series, so they could be bunch-connected to a single electrical power supply. Depending on their electrical and operational characteristics for the test, other skin-heaters were single connected to their dedicated power supply. In order to provide the required energy for the test heaters, 98 electrical power lines were used for this test of the Amazonia-1 thermal model. From these, 49 lines were dedicated to external heat loads, 25 for the thermal dissipation on the dummies and 24 for the heaters belonging to the thermal control of the spacecraft. All the electrical power supplies were remotely operated and controlled by computers, and their settings and electrical output data were properly recorded during the whole test.

For the Amazonia-1 TM external surfaces, the adopted philosophy was to cover them completely with skin-heaters, in this way simulating the absorbed heat flux portion of the thermal radiation that impinges the spacecraft during its orbital flight, for each case study.

4. The test set-up

After finishing its preparation and instrumentation, the Amazonia-1 thermal model was then loaded into the LIT-INPE 6m x 8m Space Simulation Chamber. The adopted philosophy was to hang the spacecraft from the thermal-vacuum chamber upper monorail by using 4 (four) stainless steel cables.

Figure 3 shows a schematic of the adopted lifting device to properly hang the Amazonia-1 spacecraft from the Thermal-Vacuum Chamber upper monorail. This mechanical device was properly covered with MLI (Multi-Layer Insulation) and also instrumented with skin-heaters and temperature sensors, as required for its thermal control during the test running.

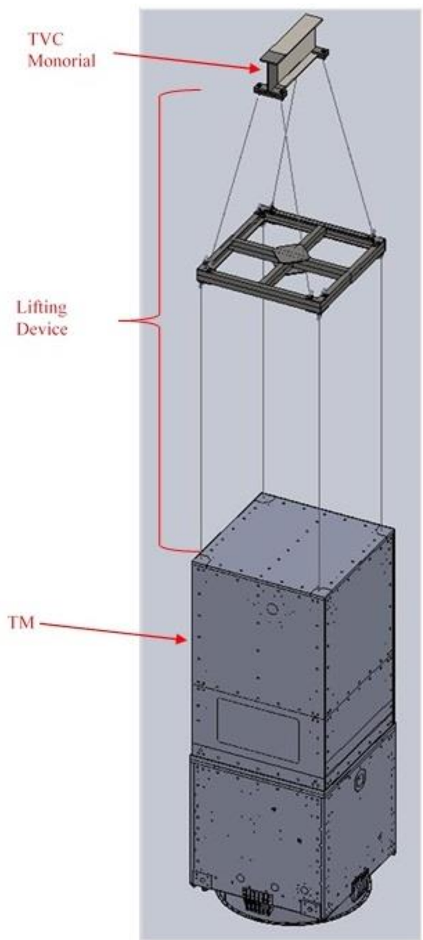

Fig. 3 - Spacecraft lifting device

In order to minimize heat conduction through the hanging fixture, Teflon® bushes were used on the spacecraft attachment hard points. The mailbox-shape configuration of this testing facility was very useful to load the spacecraft in a safe and straightforward way (see Figure 4).

After the installation of the spacecraft in the thermal-vacuum chamber, it was electrically grounded to the chamber main structure.

The 6m x 8m Space Simulation Chamber is located in the LIT-INPE main Hi-Bay, 100,000 Class Clean Room area, temperature controlled to 23ºC ±2ºC, humidity regulated from 40% to 60%. This testing facility is provided with black-painted aluminium thermal shrouds that can be operated with liquid or gaseous nitrogen, with a temperature range of -196ºC to +150ºC.

In order to provide the required high-vacuum conditioning for the test, a comprehensive set of vacuum pumps including the primary pumping system, a 3,200 l/s turbomolecular pump and three helium operated cryogenic pumps is able to bring and to maintain the pressure down to the 10^{-7} mbar range.

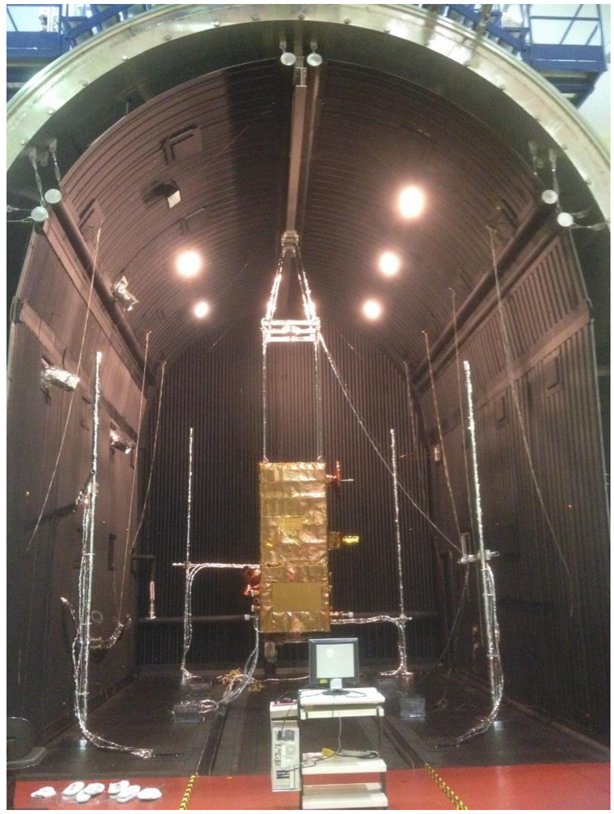

Fig. 4 - TM loaded into the LIT-INPE 6m x 8m Space Simulation Chamber

The spacecraft was positioned roughly in the centre of the chamber in order to optimize its distance to the chamber thermal shrouds. All the cabling coming from the skin-heaters installed on the spacecraft surfaces was properly connected to the power supplies through the dedicated chamber feedthroughs. In the sequence, all the temperature sensors (thermocouple Type T) were properly connected to the Data Acquisition System, using the chamber feedthroughs. For this particular test, 214 thermocouples were used for the temperature monitoring of the spacecraft and the test setup surfaces. Other significant amount of thermocouples was used to monitor and to control the chamber shroud temperature during the test. Some thermistors were also installed in the TM for this testing campaign.

In order to monitor any possible contamination during the test, 4 (four) cryogenic-cooled quartz crystal microbalances were positioned around the spacecraft. In addition, wipe tests were also carried out on top of S/C surfaces and on the chamber thermal shrouds before and after the thermal-vacuum test. Although not a flying model, it was very important to monitor any alteration of the thermal optical properties of the TM surfaces caused by a possible deposition of diverse materials, considering the significant dependence of the surfaces on the passive thermal control of the spacecraft. A 1-300 a.m.u residual gas analyser was also used during the whole test, monitoring any significant gas released from the spacecraft or test set-up, complemented by the installation of 4 witness plates positioned next to the door, central region and end of the chamber thermal shroud, and also next to the scavenger plate.

TEST CONFIGURATION:

During the Thermal Balance Test (TBT), the following thermal conditions were simulated:

a) Deep space cold environment, by using the Thermal-Vacuum Chamber (TVC) cold walls, holding high thermal absorptivity properties;

b) Orbital thermal loads in terms of thermal radiation absorbed by spacecraft surfaces, by using the skin-heaters attached to the external surfaces of the S/C;

c) Heat dissipated by spacecraft electronic equipment, according to their modes of operation, by using skin-heaters installed on the equipment dummies.

d) Heat dissipated by the spacecraft thermal control system

The heating of the spacecraft thermal control system was simulated by skin-heaters and thermistors connected to a special control set-up that used the same algorithm for the thermal control of the flight model. A total of 47 thermistors, 10kΩ @ 25°C, were installed on the spacecraft for the control of the power supply system of the battery heaters, but also in the payload module, propulsion subsystem and in the wide-field imager (WFI).

5. Development of the Amazonia-1 TM Thermal Balance Tests

TEST OBJECTIVES:

The main objectives of the thermal balance tests of the Amazonia-1 TM were:

a) To verify the performance of the spacecraft thermal design when imposing the flight thermal conditions;

b) To experimentally confirm the thermal properties estimated for the thermal control subsystem such as thermal resistance at the mechanical interfaces, multi-layer insulation (MLI) efficiency, effective conductance on the panels etc.;

c) To obtain experimental data to verify, validate and to adjust the mathematical thermal model.

The rolling main door of the LIT-INPE 6m x 8m Space Simulation Chamber was closed on November 13th, 2015, and the pumpdown sequence started, firstly using a set of two mechanical pumps and two roots blower pumps in order to reach the 10^{-2} mbar range, then a turbomolecular pump to get the vacuum in the 10^{-4} mbar range, and finally three 52” cryogenic pumps in order to obtain the required high-vacuum of 10^{-6} mbar or better, allowing the start of the thermal tests. During this sequence, at the pressure of 10^{-2} mbar a 3.0m^2 scavenger plate was flooded with liquid nitrogen in order to effectively participate in the chamber evacuating process by collecting water vapour and some other possible condensable gases.

The six thermal zones of the chamber shroud were then thermally conditioned, firstly by operating them in the gaseous nitrogen (GN2) mode during the cooling down from room temperature to -180ºC, then transferring the thermal system to the liquid nitrogen (LN2) mode to maintain the temperature of about -196ºC during the remaining part of the Amazonia-1 TM thermal balance test.

After that the actual thermal balance test of the spacecraft started, when a pre-programmed sequence of thermal dissipation inside and on the external surfaces of the spacecraft, by using the installed skin-heaters, was accordingly executed.

For the thermal-balance test, 3 (three) test cases were simulated on the Amazonia-1 TM: a *Hot Case*, a *Cold Case* and an *Emergency Case*. These test cases were complemented by a steady state and a transient condition. The steady state conditioning was focused on the verification and adjustment of the thermal mathematical model, while the transient condition was used for the evaluation of the performance of the design of the spacecraft thermal control subsystem.

In general, the whole test was formally divided into 9 phases, and they were:

Phase 1: Obtain the high-vacuum condition

Phase 2: Hot Case in steady state

Phase 3: Hot Case in transient condition

Phase 4: Cold Case in steady state

Phase 5: Cold Case in transient condition

Phase 6: Emergence Case in steady state

Phase 7: Emergence Case in transient condition

Phase 8: Returning of the TVC shroud, TM and internal set-up to room temperature

Phase 9: Thermal-Vacuum Chamber venting to ambient pressure.

During the whole test, the temperature convergence for the steady state conditions was obtained through the use of 28 monitoring points on the spacecraft.

DATA ACQUISITION SYSTEM:

The Data Acquisition System used to support the Amazonia-1 Thermal Model Thermal Balance Test was mainly composed by:

- 8 x data scanners
- 26 x internal modules
- 2 master computers
- a significant number of large screens for real-time data monitoring

This system presented the following main characteristics and performance:

a) temperature measurement:
- Type T (Cu/Cn) thermocouples
- Accuracy in the range -160ºC to +150ºC: 0.5ºC

b) DC voltage measurement:
- accuracy of ± 0.0027% of reading
- resolution related to 1V, 5-1/2 dig.: 1 μV

THE DEDICATED POWER SUPPLY SYSTEM:

The system dedicated to provide electrical power to the spacecraft and test set-up heaters was mainly composed by:

- 100 x power supplies (1500W, 760W, 750W)
- 5 routers, one for each set of 20 power supplies
- 1 router as interface between scanner and main routers
- 1 set of shunt-boxes, to interface the power supplies, the scanners and chamber feedthroughs
- dedicated software for the proper operation and control of the power supply system.

The Thermal Balance Test of the Amazonia-1 TM was actually accomplished in two sequential parts. After running from November 16th to 21st, the test was interrupted in a controlled and managed mode and put into halt for 9 days, in order comply with Institution and spacecraft program schedule. During this recess period, the chamber was maintained under rough vacuum of approximately 10^{-2} mbar and at room temperature. The Thermal Balance Test was then resumed on December 1st, running until the 7th when it was formally stopped and terminated, successfully completing the whole thermal balance testing program. Figure 6 shows the complete test profile as it actually was performed, and in Figures 7, 8 and 9 an example of temperature development on a particular equipment, the temperature developed on the TVC thermal shrouds - part 2, and the vacuum on the TVC - part 2, can be respectively found.

Fig. 5 - Electrical Power Supply System to spacecraft and set-up heaters

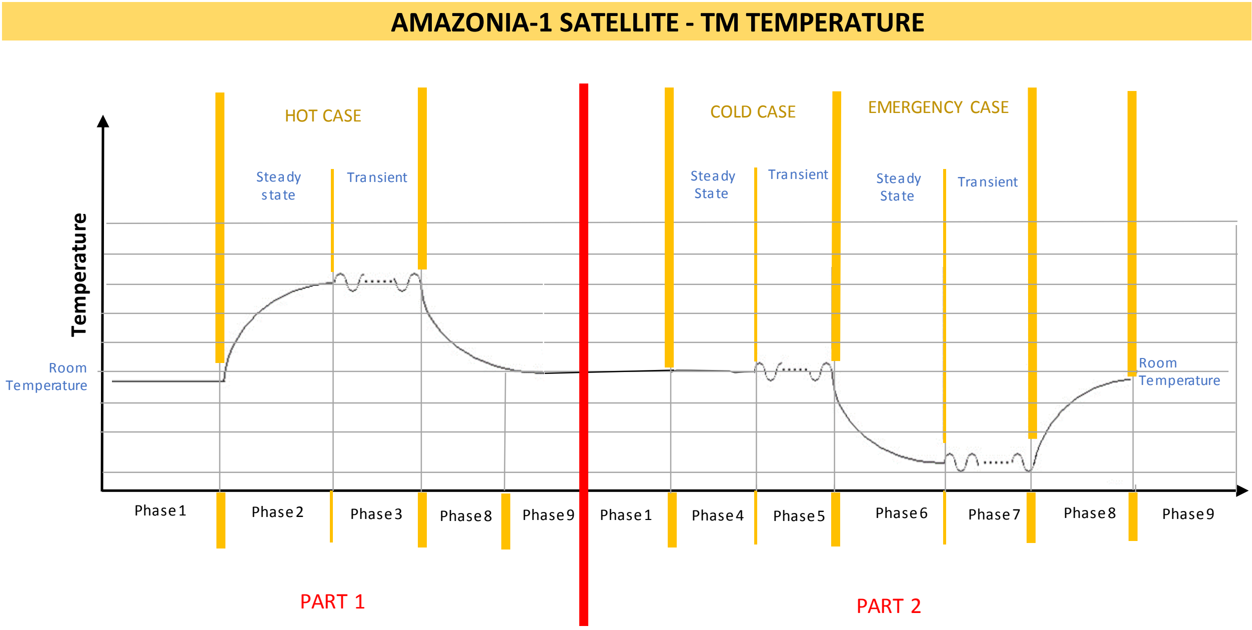

Fig. 6 - Amazonia-1 Thermal Model Thermal-Vacuum Test Profile

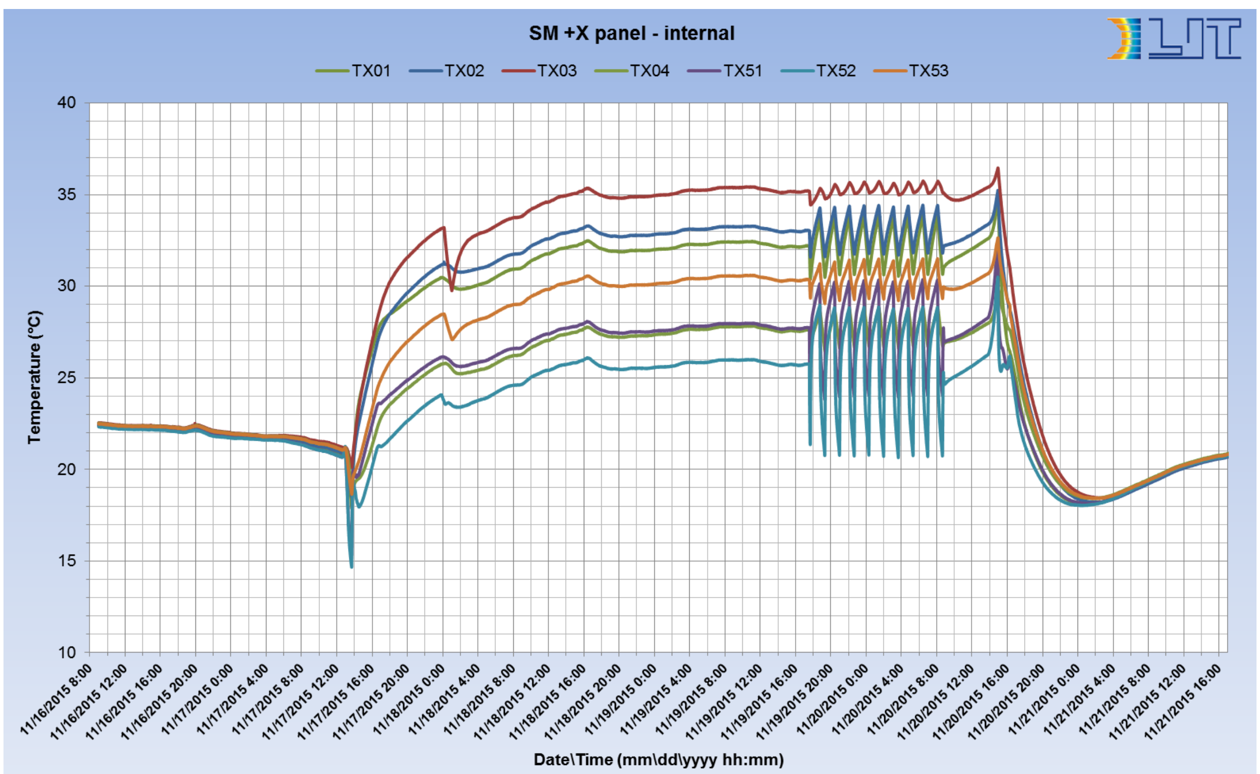

Fig. 7 - Example of Temperature Development at an S/C Section During the TBT

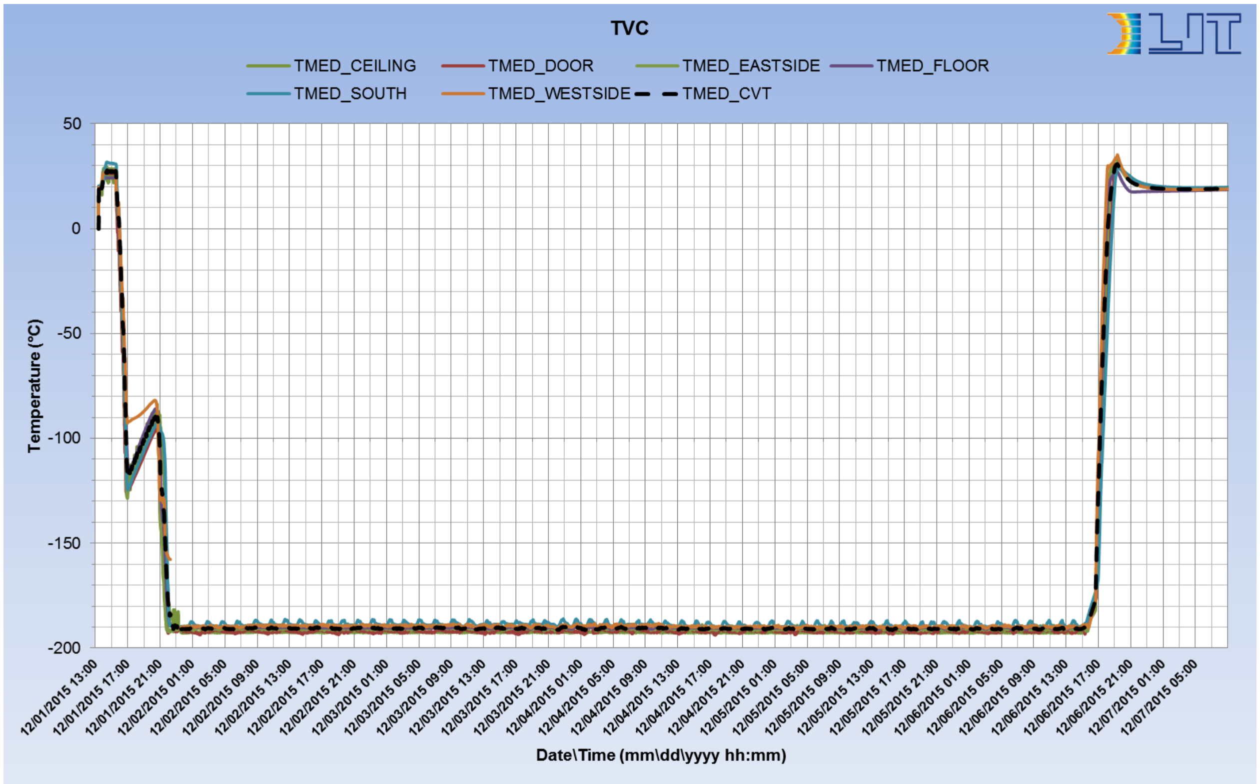

Fig. 8 - Temperature on the TVC Thermal Shrouds - part 2 of TBT

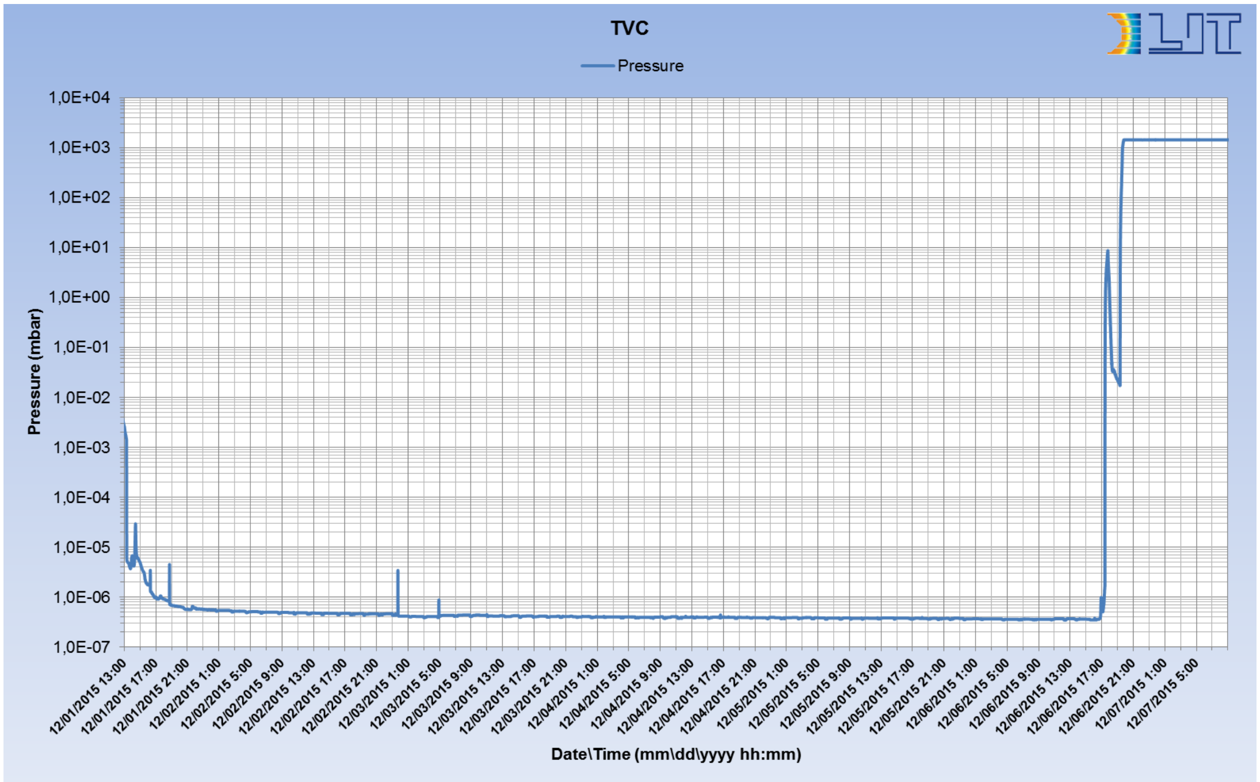

Fig. 9 - Vacuum Level on the TVC - part 2 of TBT

6. Results and Discussion

During the whole period of the 13 days of the test, the 6m x 8m Space Simulation Chamber, and the test set-up including the Power Supply System and the Data Acquisition System, all performed flawless with no recorded issue at all.

At a rate of one full scan every 30s, a significant amount of data was collected, including temperature from the spacecraft, the test set-up, and from the thermal-vacuum chamber shrouds, also voltage and current data from the Power Supply System, all these properly recorded for further analysis by the thermal engineers.

The procedure of cooling down of the chamber thermal shrouds, firstly by using gaseous nitrogen to reach the switching low-temperature point, and then moving to the liquid nitrogen operating system, proved to be quite adequate in order to perform this test with overall lower consumption of nitrogen. The effective running time of this test was 208 hours.

The philosophy of breaking down the Thermal Balance Test in two separate periods was unique for this Laboratory and actually presented a distinctive and special point: during the recess period, and making good use of the data collected from the first part, a deeper and updated review of the mathematical thermal modelling of the spacecraft could be performed, in this way optimizing the setting of the Thermal Balance Test inputs, an adjustment of the test parameters, reducing the time required for the temperature convergence, in this way improving the performance of the second part of the TBT.

In terms of data correlation, the post testing analysis showed that the temperature deviation between the mathematical thermal modelling prediction and the obtained data from the thermal-vacuum test as measured by the thermocouples installed on the spacecraft surfaces was between ±5°C for the majority of the subsystems, and this was considered as a good result.

Although the thermal shrouds of the LIT-INPE 6m x 8m Space Simulation Chamber are able to operate in gaseous or liquid nitrogen mode, for this particular test it was adopted the LN2 mode for the majority of the test, using the GN2 mode only for the transient phases of the thermal shrouds from the ambient temperature to the coolest deep-space simulation temperature, and vice-versa, and this proved to be quite adequate once it ensured a significantly lower nitrogen consumption for the test as a whole.

As far as the contamination topic is concerned, the during-the-test and the post-testing analysis showed that no significant issue was observed or recorded, which proved that the chamber, the test set-up and the spacecraft, all were appropriately clean.

7. Conclusion and Final Comments

The Amazonia-1 Thermal Model Thermal Balance Test was performed at the Integration and Testing Laboratory - LIT, from the National Institute for Space Research - INPE, in Sao Jose dos Campos, SP, Brazil, from November 13th to December 7th, for the required qualification of the thermal design and thermal control subsystem of the spacecraft.

This TBT was considered as a complete success, with all the collected test data recognized as extensively meaningful and very satisfactory for the thermal engineers.

The distinctive approach of this particular Thermal Model Thermal Balance Test of interrupting it, maintaining the chamber under rough vacuum at room temperature, and then resuming it a few days later proved to be with no harm to the test itself or to the spacecraft and test set-up, if done with the precautions of stopping at a safe and appropriate moment of the programmed test profile.

8. Acknowledgements

The authors would like to thank the LIT thermal-vacuum tests team for the preparation and execution of the Amazonia-1 tests, and the Brazilian National Institute for Space Research - INPE for the support on the presentation of this work at the 67th International Astronautical Congress.

9. References

[1] Amazonia-1 TM TBT Specification, INPE, 2015

[2] A820000-SPC-009_04 – Amazonia-1- Satellite Environmental Specification, 2015

[3] LIT05-AMZ1-TP-001- Procedimento para Realização do Setup Mecânico do Ensaio Vácuo-Térmico do Satélite Amazonia-1

[4] LIT01-LIT01-OP-007 - Procedimento de Operação da Câmara Vácuo-Térmica 6m x 8m

[5] LIT01-AMZ1-TR-002 - Amazonia 1 TM Thermal Balance Test Report, 2016