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Thermal Balance and Thermal Vacuum Test of the CBERS 4A Satellite Performed at INPE, Brazil.

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Abstract

CBERS-4A is part of the China-Brazil Earth Resources Satellite cooperation program, as a spacecraft dedicated to remote sensing purposes. Measuring approx. 1.8 x 2.0 x 2.6 m, weighing approx. 1730 kg, and carrying multispectral, panchromatic wide-scan and wide-scan cameras, this satellite was placed in a distance of 778 km, synchronous orbit of the sun in December 2019 by the Chinese launch vehicle Long March 4. The Thermal Balance and Thermal Vacuum Tests were carried out from March 18 to April 5, 2019 at the Integration and Testing Laboratory (LIT), a laboratory subordinated to the Manufacturing, Assembly, Integration and Testing Coordination (COMIT), which is a division of the Brazilian National Institute for Space Research (INPE). As one of the critical phases of the CBERS 4A assembly, integration and testing campaign, the thermal balance test was carried out to verify the performance of the thermal design under flight conditions and generate useful information for adjusting and refining the thermal mathematical model (TMM) while the main objective of the Thermal Vacuum Test was to test the functionality of the CBERS 04A under extreme thermal conditions, in a high vacuum environment. For that, a space simulation was carried out in the Thermal Vacuum Chamber CVT 6m x 8m of the LIT, and this remained during the entire test at a temperature of -190C and a vacuum lower than 1E-6 mbar, simulating deep space and to simulate the thermal loads external surfaces that impinge on the surfaces of CBER 4A, the satellite was dressed around all its faces by an array of infrared sources, in the form of frames of electrical resistance tapes.

Keywords: Satellite, Thermal Balance Test, Thermal Vacuum Test, Thermal Control System, Infrared Array, CBERS 4A.

Nomenclature
A – Amperes
°C – Celsius Degrees
K - Kelvin
Kg – Kilogram
Km – Kilometer
m – Meter
mbar - Millibar
Pa - Pascal
Q or q – Heat Flux
T1 to T3 – radiometer temperature
Tav - average temperature of the radiometers of each IRA
Tj - target temperatures of each IRA
V – Volts
W – Watts
W/m2 – Watts per squared meters
% – Percentage

Acronyms/Abbreviations
AIT - Assembly, Integration and Testing
AOCS - Attitude and Orbit Control System
BOT – Beginning of the test
CAST – Chinese Academy of Space Technology
CBERS – China-Brazil Earth Resources Satellite
COMIT - Manufacturing, Assembly, Integration and Testing Coordination
DAS - Data Acquisition System
DCS - Data Collection Subsystem
DDR - Digital Data Recorder
DTS - Data Transmitter System
EGSE - Electrical Ground Support Equipment

EOT - End of the Test
HP – Heat Pipe
INPE – National Institute for Space Research
IRA – Infrared Radiation Array
LIT - Integration and Testing Laboratory
MLI – Multilayer Insulation
MUX - Multispectral Camera
NiCr – Nickel-Chrome
OBDH - Onboard Supervision
OSR - Optical Solar Reflector
PID – Proportional-Integral-Derivative
PM - Payload Module
PSCS - Power Suply and Control System
RM – Radiometer
SAG - Solar Generator (Solar Panel)
SEM - Space Environment Monitor
SM - Service Module
TC – Thermocouple
TBT – Thermal Balance Test
TMM - Thermal Mathematical Model
TMP - Temperature Monitor Points
TCSS - Thermal Control Subsystem
TSLC - Taiyuan Satellite Launch Center
TVT – Thermal Vacuum Test
TVC – Thermal Vacuum Chamber
XSCC - Xian Satellite Control Center.
WFI - Wide Field Imaging Camera
WPM - Wide-Scanning Multispectral and Panchromatic Camera

1. Introduction

CBERS 04A the sixth satellite of the CBERS family, was successfully launched and placed into orbit in the early morning hours of December 20, 2019, by the Long March 4B Rocket, from the Taiyuan Satellite Launch Center (TSLC), in China. The launch was attended by experts from the National Institute for Space Research (INPE), the Chinese Academy of Space Technology (CAST) and the Xian Satellite Control Center (XSCC) [1]. The assembly, integration and testing (AIT) activities of the CBERS 04A satellite were carried out at the Integration and Testing Laboratory (LIT), a laboratory subordinated to the Manufacturing, Assembly, Integration and Testing Coordination (COMIT), which is a division of the INPE located in São José Campos / SP – Brazil. The AIT started in November 2017 and ended in April 2019. The CBERS 04A, illustrated in figure 1, is a spacecraft dedicated to remote sensing purposes and its main mission parameters are shown in the table 1. The Space Simulation Test for the qualification of the Thermal Control Subsystem (TCSS) of the CBERS3&4 satellites was carried out at LIT/INPE, Brazil, in 2009, the reference [2] describes this work; the Space Simulation Tests of acceptance CBERS 3 and CBERS 4 flight models were performed at the Space Center in Beijing, China respectively in 2012 and 2014. The Space Simulation Tests, Thermal Balance Test (TBT) and Thermal Vacuum Test (TVT), of acceptance CBERS 4A satellite, the main subject of this paper, were performed in Brazil from March 18 to April 5, 2019 at the LIT. The main objectives of the TBT were to verify the performance of the thermal design in the flight conditions and to generate useful information to adjust and refine the thermal mathematical model (TMM) while the TVT main purpose was to test the functionality of the CBERS 04A at the extreme thermal conditions, under high vacuum environment. The CBERS 04A TBT/TVT tests philosophy was the simulation of the heat flux incident on the satellite made by a set of Infrared Radiation Arrays (IRA) installed close to surfaces over radiators areas and of the cameras baffle regions, and by film heaters installed on the external surfaces of the multilayer insulation (MLI). A set of radiometers were used to measure the heat flux coming from IRA and to control the IRA power. The temperature and pressure in thermal vacuum chamber, during the TBT and TVT, were lower than 100K and less than 1.3×10^{-3} Pa. The facility used was the 6x8m TVC the thermal setup was composed of 31 IRAS and 36 MLI heater circuits that were controlled by a Power Supply and Control System (SSCP) composed of 100 DC power supply and were used 172 thermocouples, 156 thermistors and 85 radiometers.

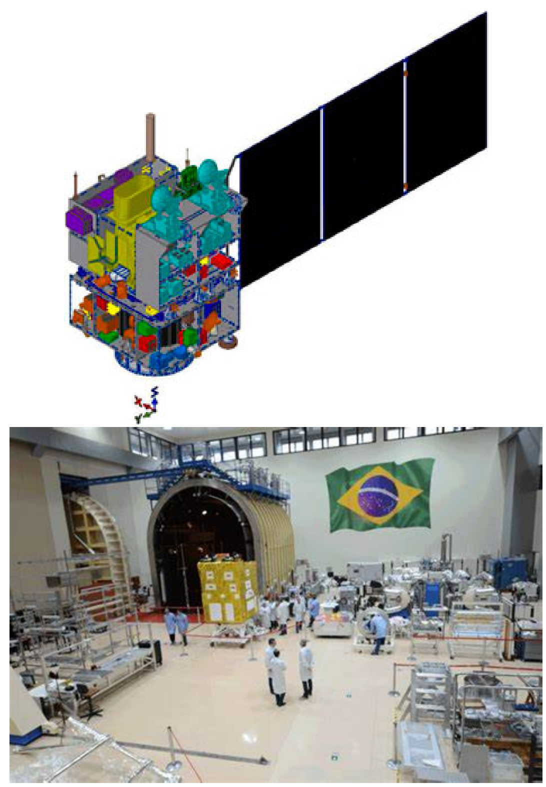

Fig. 1. CBERS 4A

Table 1. Mission parameters of CBERS 04A

CBERS-04A	
Total mass	1730 kg
Useful lifetime	5 years
Generated power	2100 W
Data rate	900 Mbps/s
Dimension of the satellite body (m)	1.8 x 2.0 x 2.6
Dimension of solar panel (m)	6.3 x 2.6
Type	Sun-Synchronous Orbit
Altitude	628,6 km
Inclination	97,89 degrees
Local time at the descending node	10:30 a.m.
Local time stability at the descending node	± 10min
Orbital period	97.25 min
Revolution/day	14 + 25/31
Repetition cycle	31 days
Trace stability at the equator	± 5 km
Interval between ajacent tracks	3 days

2. Test Facilities and Methods

2.1 Tests philosophy

The CBERS 04A TBT and TVT followed the same test philosophy already used for CBERS 3&4 [3,4,5]. A simple and reliable methodology will be used, where the simulation of the incident heat flux on the satellite is made by film heaters installed on the MLI external surfaces and also by the IRAs installed near the surfaces where the MLI heater circuits cannot be directly installed, for example over radiator areas and in the regions of the camera baffles and on the OSR radiators. The CBERS 04A TBT necessary to qualify the thermal design and the satellite TMM, will be divided into 2 cases that will simulate the minimum and maximum predicted temperatures for the satellite under extreme cold and hot flight conditions. Transient cases will be performed in order to simulate environmental and functional satellite conditions in orbit, including extreme cold and hot thermal cycling environment. The CBERS 04A TVT, necessary to verify the proper operation for the satellite as an integrated system and to correct workmanship on the assembling and integration of the flight equipment in the satellite, will consist of 4 cycles of low and high acceptance-level temperature extremes, in high vacuum environment.

2.2 Satellite description

The TBT/TVT satellite configuration is shown in Fig. 2. The satellite X Band antennas was installed on the CBERS 4A on the folded position (launch configuration), and ectrical antenna simulators was put outside the TVC for function test in the TVT. Other antennas was not installed on the CBERS 4A test model. Star sensors have radiometers on the center of the baffle window, to obtain the IRA heat flux in during the test. SAG was not installed on the CBERS 4A test model. The Hydrazine tanks was filled with pure helium gas with pressure of about 1.7 MPa. The adapter cylinder and V-clamp band were not installed. Current flowed through BAPTA during TBT and TVT, so there was no need to simulate heat dissipation during testing by using heaters.

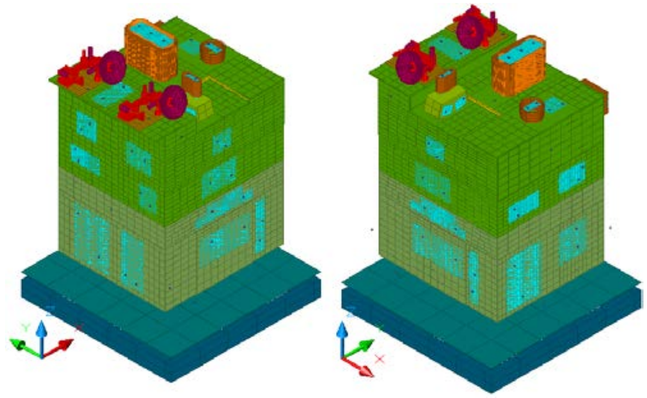

Fig. 2. 3D images of the CBERS 4A in TBT/TVT configuration

2.3 Test setup

2.3.1 Infrared cage system

The Infrared Cage System [6,7] is composed of thirty-one (31) IRAs panels that must be assembled a specific distance around the CBERS 4A satellite to reproduce the heat flux absorbed by the external surfaces and its satellite OSR radiators, payload cameras radiators and baffles. Figure 3 shows the IRA panels that integrate the Infrared Cage System projected for the CBERS-04A TBT/TVT.

The IRA configuration [8] that is a set of Nickel-Chrome (NiCr) strips, nuts and bolts were used to install the strips on the teflon sheet supported in the aluminum plate. The assembly was also required stainless steel springs whose purpose was to keep the stretched strip to improving the heat flux uniformity. The spot welding was used to connect the set of strips in series.

2.3.2 Radiometers

Radiometers (RM) are radiative heat flux sensors that measure incident and absorbed thermal radiation flux by a surface, the 85 radiometers were installed for the CBERS 4A TBT/TVT, where 73 were used to IRA control and 12 for monitoring. The local, identification and position of each radiometer is given in the references

[6,9]. The figure 4 illustrates and shows the radiometers installed in the CBERS 4A surface.

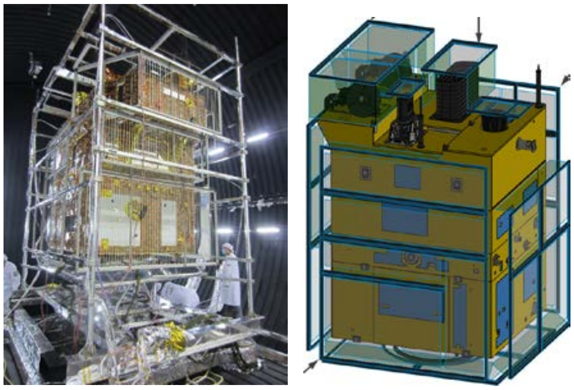

Fig. 3. Infrared cage system

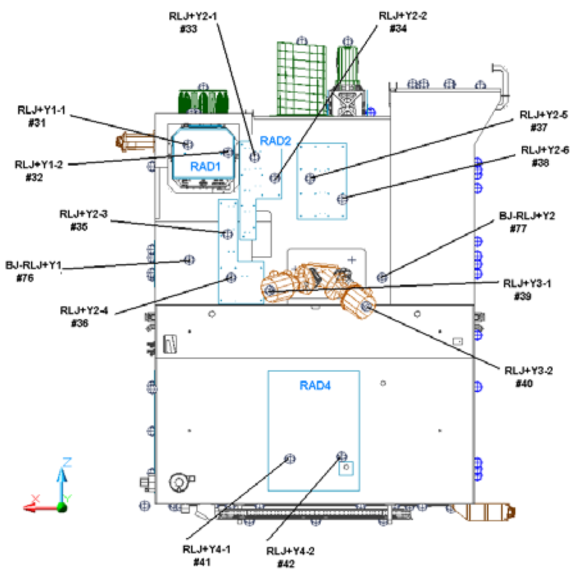

Fig. 4. Radiometers installed in the CBERS 4A surface

2.3.3 ***Skin heaters***

Applied over the MLI blankets in order to simulate the external heat loads, details in reference [10]. MLI heater circuits are illustrated in figure 5.

2.4 Facilities

2.4.1 Thermal vacuum chamber

The 6x8 m TVC at the LIT/INPE, reference [11], is a vacuum chamber with useful dimensions compatible with the specimen dimensions. The pressure in the 6x8 m TVC shall be less than 1.3×10^{-3} Pa during the test. The temperature of the heat sink (TVC shroud) shall be less than 100K (-173.15°C) during the TBT and TVT. The temperature uniformity of the heat sink shall be better than ± 5K during the test. The hemispherical emissivity of the heat sink surface shall be at least 0.90.The figure 6 shows the schematic drawing of the CBERS 4A inside the 6x8 m TVC.

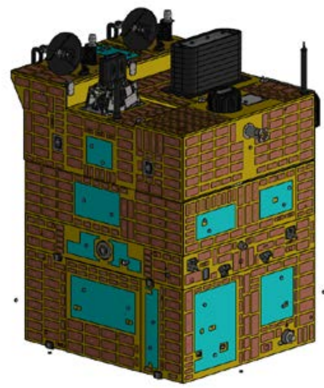

Fig. 5. MLI heaters circuits installed on +Y and –X CBERS 4A Face

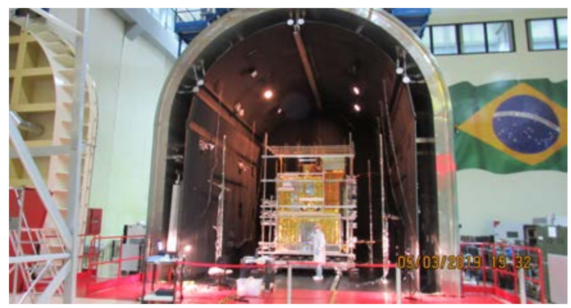

Fig. 6. CBERS 4A inside the 6x8 m TVC

2.4.2 Data acquisition system

The data acquisition system (DAS) for acquisition of the temperature and pressure in the TVC consist of 7 Scanner: Agilent 34980A/Internal Model: 34921T, 10 PC: Pentium (R) 4CPU 3,20 GHz 1G RAM, Software: DATAqs, DATAView and DATACalc, MAX, ASM View – Version 4.0.5 – Adixen –Alcatel Vacuum Technology.

2.4.3 Power supply and control system

The power supply and control system (PSCS) provides power supply and control for IRAs, MLI heater circuits, support interface ring and thermal control RF cables. The PSCS consist: Data Acquisition (Agilent Technologies 34980A 2 scanner Agilent 34980A/Internal Model 34921T; Temperature controller 4 controller Contemp C709, instruction manual [RD7]); Power supply (40 DC power supply Agilent 300V5A 1500W, 40 DC power supply Agilent 150V5A 750W, 20 DC power supply Agilent 80V9.5A 775W); Computer (4 PC Pentium (R) 4CPU 3.20 GHz 1G RAM, Win 7 - 32bits / Intel Core i5 / 4GB / ter7, Win 7 - 64bits / AMD Athlon Dual Core / 4GB / Ter 42); Software (power supply controller; recipe editor; plotelog).

2.4.4 Contamination analysis laboratory

Chemical contamination analysis of the Thermal Vacuum Chamber were performed by LIT's Contamination Analysis Laboratory by using the method of Infrared Spectrometry on witness plates and mass spectrometer.

2.4.5 Vacuum sensor

The measurement of the vacuum level inside the TVC were performed by: Primary vacuum (Pirani - active pirani gauge / active digital controller - Edwards limited (instrument range: 1E-03 to 1E + 03 mbar)); High vacuum (Inverted magnetron / active digital controller -Edwards limited (instrument range: 1E-07 to 1E + 02 mbar)).

2.4.6 Temperature sensor

The sensors used to measure the temperature of the satellite and TVC have the following specification: Thermocouple, type TT-T-30, Manufactures: Omega. The total uncertainty for the temperature measurement, including sensor, installation and data acquisition errors are:

+/- 0.7ºC for 0ºC < T < 350ºC
+/- 1.2ºC for –200ºC < T < 0ºC

2.5 Test instrumentation requirements

2.5.1 Thermocouples

For CBERS 4A TBT/TVT were installed a total 172 thermocouples, where 100 were installed on the panels and equipment, the positions these thermocouples are shown in reference [3], 26 on the interface ring, 34 on the kart, 12 in the RF thermal control device. All these thermocouples were monitored and recorded during the test.

2.5.2 Thermistors

All the 156 TCSS temperature telemetry thermistors were also monitored during the test.

2.5.3 Radiometers

The 85 radiometers were installed for the CBERS 4A TBT/TVT, where 73 were used to IRA control and 12 for monitoring. The local, identification and position of each radiometer is given in [9].

2.5.4 Sample requirements

Mass spectrometer and Samples (witness plates) were used to monitor the contamination from the vacuum chamber. The contaminations detectors were installed in the vacuum chamber.

2.5.5 ***Cables requirements***

All cables connected with the satellite, such as heating cables, temperature measuring cables, signal cables, power supply cables, data transferring signal cables were led out through the airproof flanges on the vacuum chamber wall. Generally, cables of heaters on the satellite are connected with the corresponding cables of vacuum chamber by means of connector plugs. While cables of temperature measuring sensors are connected with the corresponding cables of vacuum chamber by means of connector plugs.

3. Test description

3.1 Test sequence

The main test are Bakeout, 24 hours; TBT, one cycle – cold case and hot case; and TVT, 4 cycles. The test sequence includes 24 phases, identified by a number or by a number followed by the letter a (transition phases), below a description of each phase is given.

3.1.1 Beginning of the test (BOT)

Prior the beginning of the test, the TVC door is closed with the satellite turned OFF and no AIT activity to let the temperatures to equalize for 12 hours, after that, the temperatures of thermistors (TMB telemetry from OBDH) and thermocouples are checked by thermal people to assure that all sensors are reading the same temperature. Then depressurizing of the chamber or primary vacuum is started until the pressure at the chamber reaches 0,01 mbar at this moment the cryogenic pumping can be enabled and chamber will reach the high vacuum (<$1.3x10^{-5}$ mbar). This phase is the beginning of the test (BOT).

3.1.2 Satellite cleaning phase - phases 1a and 1

3.1.2.1 Phase 1a (transient) - cooling down

This phase started when the temperature and vacuum conditions in thermal vacuum chamber (TVC) are equal environmental temperature and Pressure is less than $1.3x10^{-5}$mbar. Due to specific requirement of camera optic surfaces contamination, the IRAs, 21, 22 and 24, may need increased power during cooling down and rewarming transition periods. The wattages for IRAs 21, 22 and 24 are respectively 62W, 244W and 43W.

3.1.2.2 Phase 1 (bake-out or cleaning phase)

Phase 1 started when the temperature of vacuum chamber heat sink is lower than 100K. In the phase 1, the satellite equipment will be kept at high temperature with IRAs and MLI heater circuits. The IRAs (table 3) and MLI heater circuits (table 4) will be controlled with the same values of TBT hot case. The Service subsystems of the satellite will remain operating while the Payload subsystems will be kept at a non-operating status. The cleaning phase shall last at least 24 hours.

3.1.3 The phases 2a to 3 represent the TBT

3.1.3.1 Cold case (phases 2a and 2)

Cold Case BOL transient: The summer solstice, solar constant is minimal. External heat fluxes are simulated as average of orbit period. Optical properties of all thermal coating are at BOL condition. Equipment in PM shall be in stand-by condition. Other instruments in the SM satellite shall be operating at their minimum heat dissipation modes. The battery and hydrazine tank heaters shall work. Battery dissipation is at its BOL condition, DCS is in stand-by.

The data input of the IRAs is **Tj** (IRA target temperature, table 3) and of the MLI heaters circuits is **Q - power W** (cold case, table 4). The TBT cold case finish when the convergence criteria for Temperature Monitor Points (TMP, table 5) is reach. In the TBT cold case the convergence will be achieved when the temperature variation on the monitoring points satisfy one of the following conditions:

a. The temperature fluctuation is not bigger than ±0.5 ºC in 4 continual hours;

b. the monotonous temperature change is less than 0.1ºC/hour in 4 c0ontinual hours. After the first 4 hours the convergence is verified at each minute.

It is expected that in the end of TBT cold case (phase 2) the thermal control heaters will be operating at maximum power.

Note: For BDR and Shunt shall be used the TBT hot case convergence criteria.

3.1.3.2 Hot case (phases 3a and 3)

Hot Case EOL transient: The winter solstice, solar constant is maximal. Solar absorptivity of thermal coatings shall be taken 5-year-degeneration value (EOL). SM equipment heat dissipation values are set according to operating modes described in [4] PM equipment shall work for 12 min in sunlight (image and record) and 12 min in eclipse (playback) in each orbit according to [4]. Battery dissipation is at its EOL condition, DCS works during imaging and playback. The data input of the IRAs is **Tj** (IRA target temperature, table 3) and of the MLI heaters circuits is **Q - power W** (hot case, table 4). The TBT hot case finish when convergence criteria for Temperature Monitor Points (TMP, table 5) is reach. For TBT hot case, it is considered periodic stable when the temperature variation on the monitoring points is less than 1.0°C at the same position in orbit during 1 (one) orbit. After the first 2 (two) orbits the convergence is verified at each minute. For this Case one cycle is composed of one orbit (97 min).

3.1.4 The phases 4a to 11 represent the TVT

The TVT, necessary to check the functionality of the S/C equipment in extreme temperatures conditions under high vacuum and consist of 4 cycles according to reference [4]. Each cycle has two temperature soaks with at least 8 hours in each temperature soak. Functional tests are performed during the periods of stabilized temperature, at cold temperature levels (phases 5, 7, 9 and 11) and hot temperature levels (phases 4, 6, 8 and 10). The equipment operation mode is the same as for the TBT. Equipment with active thermal control, for example cameras, batteries, cannot increase and decrease temperature during the TVT, compared with TBT. For the cold temperature levels, the reference will be the TBT cold case (phase 2), this is the lowest measured temperature in TBT cold decreased by 5°C. For the hot temperature levels, the reference will be the TBT hot case (phase 3), this is the highest measured temperature TBT hot increased by 5 °C. The temperature difference between the TVT cold and hot shall be larger than 32°C, or at least 80% of the equipment shall reach the rules above.

3.1.4.1 Phases 4a - TVT hot case

The data input of the IRAs is **Tj** (IRA target temperature, table 3) and of the MLI heaters circuits is **Q - power W** (hot case, table 4).This phase finish when the variation rate of the TMPs (table 5) become less than 3ºC/hour in 30mins.

3.1.4.2 Phases 4 - TVT hot case

The hot case soak after 8 hours is completed, with same phase 4a data input.

3.1.4.3 Phases 5a - TVT cold case

The data input of the IRAs is **Tj** (IRA target temperature, table 3) and of the MLI heaters circuits is **Q - power W** (hot case, table 4).This phase finish when the variation rate of the TMPs (table 5) become less than 3ºC/hour in 30mins.

3.1.4.4 Phases 5 - TVT cold case

The cold case soak after 8 hours is completed, with same phase 5a data input.

3.1.4.5 Phases 6a - TVT hot case

The data input of the IRAs is **Tj** (IRA target temperature, table 3) and of the MLI heaters circuits is **Q - power W** (hot case, table 4).This phase finish when the variation rate of the TMPs (table 5) become less than 3ºC/hour in 30mins.

3.1.4.6 Phases 6 - TVT hot case

The hot case soak after 8 hours is completed, with same phase 6a data input.

3.1.4.7 Phases 7a - TVT cold case

The data input of the IRAs is **Tj** (IRA target temperature, table 3) and of the MLI heaters circuits is **Q - power W** (hot case, table 4).This phase finish when the variation rate of the TMPs (table 5) become less than 3ºC/hour in 30mins.

3.1.4.8 Phases 7 - TVT cold case
The cold case soak after 8 hours is completed, with same phase 7a data input.

3.1.4.9 Phases 8a - TVT hot case
The data input of the IRAs is **Tj** (IRA target temperature, table 3) and of the MLI heaters circuits is **Q - power W** (hot case, table 4).This phase finish when the variation rate of the TMPs (table 5) become less than 3ºC/hour in 30mins.

3.1.4.10 Phases 8 - TVT hot case
The hot case soak after 8 hours is completed, with same phase 8a data input.

3.1.4.11 Phases 9a - TVT cold case
The data input of the IRAs is **Tj** (IRA target temperature, table 3) and of the MLI heaters circuits is **Q - power W** (hot case, table 4).This phase finish when the variation rate of the TMPs (table 5) become less than 3ºC/hour in 30mins.

3.1.4.12 Phases 9 - TVT cold case
The cold case soak after 8 hours is completed, with same phase 9a data input.

3.1.4.13 Phases10a - TVT hot case
The data input of the IRAs is **Tj** (IRA target temperature, table 3) and of the MLI heaters circuits is **Q - power W** (hot case, table 4).This phase finish when the variation rate of the TMPs (table 5) become less than 3ºC/hour in 30mins.

3.1.4.14 Phases 10 - TVT hot case
The hot case soak after 8 hours is completed, with same phase 10a data input.

3.1.4.15 Phases 11a - TVT cold case
The data input of the IRAs is **Tj** (IRA target temperature, table 3) and of the MLI heaters circuits is **Q - power W** (hot case, table 4).This phase finish when the variation rate of the TMPs (table 5) become less than 3ºC/hour in 30mins.

3.1.4.16 Phases 11 - TVT cold case
The cold case soak after 8 hours is completed, with same phase 11a data input.

3.1.5 End of the test (EOT) – warming and repressurization

3.1.5.1 Warming
The TVC temperature shroud is warm of -190ºC until environmental temperature and during this period, the IRAs, 21, 22 and 24, need increased power to avoid of cameras optic surfaces contamination. . The wattages for IRAs 21, 22 and 24 are respectively 62W, 244W and 43W.

3.1.5.2 Repressurization
When TVC temperature reaches environmental temperature the high vacuum valve can be closed, and if the satellite temperatures are around the environmental temperature then the venting process of the chamber can be started until the pressure reach environmental condition, from this moment the TVC door can be open.

3.2 Test devices requirements

3.2.1 Infrared array devices
IRAS are frames with installed NiCr strips, and set of Aluminum shields, for CBERS 4A TBT/TVT were installed a total of 31 IRA frames, details of the IRAs can be shown in reference [7]. The resent a list with all IRAs, their main characteristics and preliminary estimated temperature set point. The power in each IRA was applied and controlled by the PSCS. The control was done via PID using the average temperature (Tav), given in equation (1), of the radiometers of each IRA as input parameter. Each IRA has 2 to 3 radiometers installed and the temperatures T1, T2 and T3 of equation (1) are refer to these radiometers. The set point data for the PSCS were the target temperatures (Tj) of each IRA and are shown in table 2.

$$T_{av} = \sqrt[4]{\frac{T_1^4 + T_2^4}{2}} \text{ or } T_{av} = \sqrt[4]{\frac{T_1^4 + T_2^4 + T_3^4}{3}} \quad (1)$$

3.2.2 MLI heaters circuits device
The film heaters were applied on the MLI external surfaces to simulate the required absorbed heat fluxes by the MLI according to [10]. Total 36 MLI heater circuits were used. The supply and control of power in each MLI heater circuits was done by PSCS. The table 3 shows the values of power, in the cold and hot cases, each MLI heater circuits.

3.2.3 Temperature monitor points
The convergence of the satellite temperatures during TBT and TVT was verified through temperature monitoring points (TMP) as specified in table 4 The convergences of both hot and cold temperatures soaks was considered reached when all equipment temperatures (TMPs) listed in Table 4 satisfy the criteria.

The other temperature measurement points was taken as reference.

3.2.4 Electrical tests

The EGSE teams of CAST and INPE were responsible to performed electrical tests. The equipment of the electrical setup and the electrical control room can be seen in the figure 7.

Fig. 7. CBERS 4A EGSE

4. Results

The CBERS 4A Thermal Balance and Vacuum Thermal Tests TBT/TVT specification were performed as conform de [3] and [4], was also performed a CBERS 4A Bakeout at the beginning of the test. The complete power, temperature and pressure data results are stored in medias. In this paper some results are presented by graphics as can be seen in the figures 8 to 13. The results indicate that the test was carried out within the conditions specified. From the visual point of view it can be said that the CBERS 4A satellite showed no signs of deterioration on opening the Thermal Vacuum Chamber.

5. Conclusions and commentaries

Figure 14 show the sequence and duration of the test. The CBERS 4A FM TBT/TVT started at 5:03 pm on March 20 and ended at 3 pm on April 5, 2019, totalling 382 hours and 7 minutes (16 days) of testing. The CBERS 4A TBT/TVT was conducted by the LIT Thermal Vacuum team composed of 12 professionals, working in 3 shifts; and was supported by the DAS team (5 person), Electrical support team (5 person), Building maintenance team (5 person); an AIT manager; Thermal control subsystem team (2 person); Electrical test group (15 person) and a Quality assurance's expert; totalling 46 Brazilians professionals. Ten (10) professionals from China's CAST also participated, belonging to the Thermal, EGSE and Satellite Electronics groups.

Another factor that may also indicate the relevance of the CBERS 4A TBT/TVT is its estimated cost, considering only Brazilian expenses, which is around US$ 1.5 million.

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[9] CBERS 04A TBT Radiometers Arrangement Specification. RBU14-TES-0039/00(04a). December 04, 2018.

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Table 2. CBERS 04A IRA temperature set point list

N	IRA frame code	IRA Code	*TBT COLD*	*TBT HOT*	*TVT COLD*	*TVT HOT*
			***Tj [C]**	**Tj [C]**	**Tj [C]**	**Tj [C]**
1	IRA 1	IRA +X1 PM	-63.5	-41.8	-95	-10
2	IRA 2	IRA +X2 PM	-63.4	-41.8	-95	-10
3	IRA 3	IRA +X3 SM	-63.1	-41.8	-95	-10
4	IRA 4	IRA +X4 SM	-63.1	-41.8	-95	-10
5	IRA 5	IRA +Y1 MUX	-92.8	-90.3	-92.8	-90.3
6	IRA 6	IRA +Y2 WPM	-90.8	-84.8	-90.8	-84.8
7	IRA 7	IRA +Y3 STS	-91.5	-86.4	-100	-40
8	IRA 8	IRA +Y4 SM	-93.8	-88.1	-100	-40
9	IRA 9	IRA -X1 PM	-63.7	-41.8	-95	-10
10	IRA 10	IRA -X2 PM	-63	-41.3	-95	-10
11	IRA 11	IRA -X3 PM	-63.1	-43	-95	-10
12	IRA 12	IRA -X4 PM	-63.6	-41.9	-95	-10
13	IRA 13	IRA -X5 SM	-63.4	-42.1	-95	-10
14	IRA 14	IRA - X6 SM	-63.4	-42	-95	-10
15	IRA 15	IRA -Y1 PM	-41.7	-15.8	-80	0
16	IRA 16	IRA -Y2 PM	-51.9	-23.5	-80	0
17	IRA 17	IRA -Y3 BAPTA	-61.9	-30.3	-80	0
18	IRA 18	IRA -Y4 SM	-45.1	-18.4	-80	0
19	IRA 19	IRA -Y5 SM	-48	-19.6	-80	0
20	IRA 20	IRA +Z1 MUX	-25.8	-22	-25.8	-22
21	IRA 21	IRA +Z2 MUX	5	7.9	5	7.9
22	IRA 22	IRA +Z3 WPM	5.7	9.2	5.7	9.2
23	IRA 23	IRA +Z4 WFI	-33.6	-17.5	-33.6	-17.5
24	IRA 24	IRA +Z5 WFI	4.2	8	4.2	8
25	IRA 25A	IRA +Z6 ANT-A	-26	-15.8	-50	0
26	IRA 25	IRA +Z6 ANT-C	-26	-15.8	-50	0
27	IRA 25B	IRA +Z6 ANT-B	-26	-15.8	-50	0
28	IRA 26	IRA -Z1 Battery	-85.4	-54	-85.4	-54
29	IRA 27	IRA -Z2 SM	-82.2	-51.5	-95	-30
30	IRA 28	IRA -Z3 SM	-73.9	-42.6	-95	-20
31	IRA 29	IRA -Z4 SM	-73.1	-41.7	-95	-20

*Tj- Set point temperature or IRA target temperature.

Table 3. MLI heater circuits locations

No	MLI Heater Circuit	Resistance (Ω)	area	Q - power W –TBT/TVT	
				Cold case	**Hot case**
1	MLI + X1	41,09	0,54	**87**	**127**
2	MLI + X2	41,12	0,55	**89**	**130**
3	MLI + X3	36,06	0,53	**46**	**66**
4	MLI + X4	41,05	0,13	**11**	**16**
5	MLI + X5	36,14	0,58	**51**	**73**
6	MLI + X6	41,13	0,37	**32**	**47**
7	MLI + X7	38,62	0,59	**50**	**73**
8	MLI - X1	41,06	0,55	**44**	**69**
9	MLI - X2	36,11	0,55	**44**	**68**
10	MLI - X3	44,52	0,37	**30**	**47**
11	MLI - X4	36,11	0,42	**33**	**52**
12	MLI - X5	38,59	0,58	**47**	**73**
13	MLI - X6	34,42	0,37	**30**	**47**
14	MLI - X7	33,57	0,52	**42**	**66**
15	MLI + Y1	37,05	0,69	**34**	**36**
16	MLI - Y1	31,00	0,42	**13**	**45**
17	MLI - Y2	51,13	0,42	**13**	**45**
18	MLI - Y3	50,97	0,38	**12**	**41**
19	MLI - Y4	43,59	0,53	**26**	**68**
20	MLI - Y5	51,03	0,31	**15**	**40**
21	MLI - Y 6	50,99	0,17	**11**	**25**
22	MLI - Y7	51,04	0,17	**7**	**20**
23	MLI - Y8	36,06	0,46	**17**	**54**
24	MLI - Y9	33,62	0,51	**19**	**59**
25	MLI - Y10	37,68	0,27	**12**	**32**
26	MLI + Z1	32,72	0,27	**12**	**19**
27	MLI + Z2	46,26	0,18	**8**	**13**
28	MLI + Z3	36,10	0,52	**99**	**117**
29	MLI + Z4	41,10	0,27	**52**	**61**
30	MLI + Z5	34,38	0,23	**44**	**52**
31	MLI + Z6	36,05	0,43	**82**	**97**
32	MLI - Z1	44,51	0,27	**24**	**41**
33	MLI - Z2	36,01	0,58	**81**	**142**

34	MLI - Z3	31,08	0,36	**28**	**49**
35	MLI - Z4	34,47	0,37	**28**	**48**
36	MLI - Z5	65,91	0,23	**21**	**36**

Table 4. Temperature Monitor Points (TMP) for TBT and TVT

No.	**Sensor Identification**	**Equipment Code**	**Satellite Compartment**
1	TMB110	RBCK	SM1
2	TMB109	RBCJ	SM2
3	TC28	RBCG-B	SM2
4	TMB140	RBDD-B	SM7
5	TMB162	RBGA	SM9
6	TMB148	RBEA-A	SM4
7	TMB149	RBEA-B	SM5
8	TMB152	RBFA	SM5
9	TMB146	RBDB	SM6
10	TMB111	RBCL-A	SM3
11	TMB130	RBCY	SM9
12	TMB136/TC26	RBDA	SM16
13	TMB146/TC27	RBDB	SM16
14	TMB150/TC23	RBEF-A	SM11
15	TMB187/TC18	RBNB	PM25
16	TMB189	RBOA	PM8
17	TMB167	RBHC	PM15
18	TMB170	RBJB	PM17
19	TMB174	RBJK-a	PM08
20	TMB183	RBLA-a	PM18
21	TMB165	RBHA-b	PM06

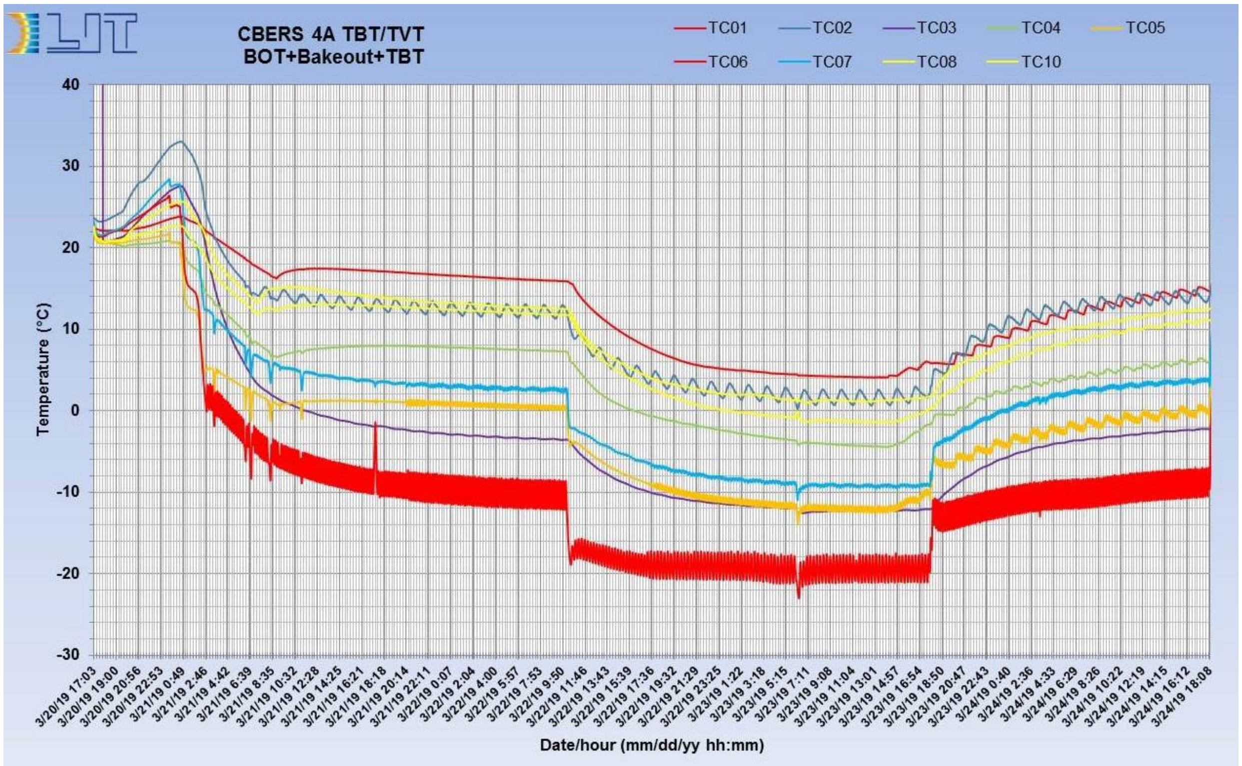

Fig. 8. The BOT + Bakeout + TBT test phases temperature profile

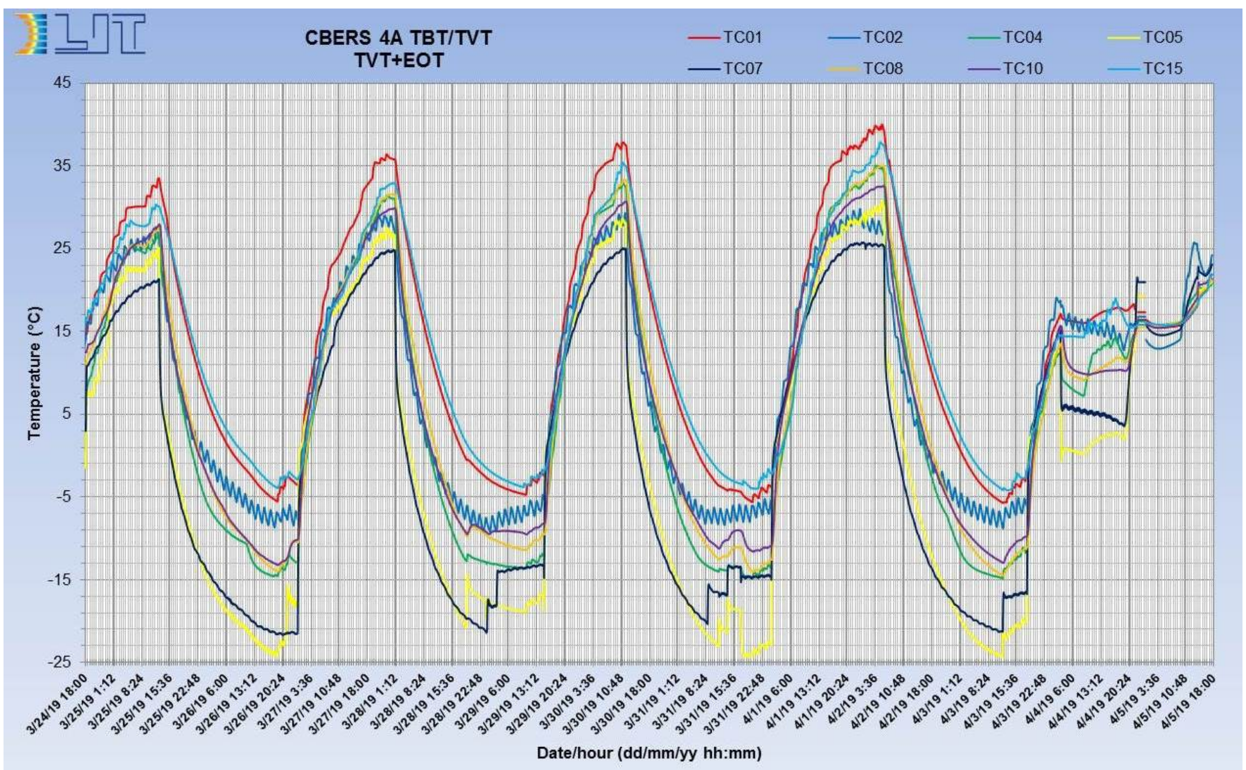

Fig. 9. The TVT and EOT test phases temperature profile

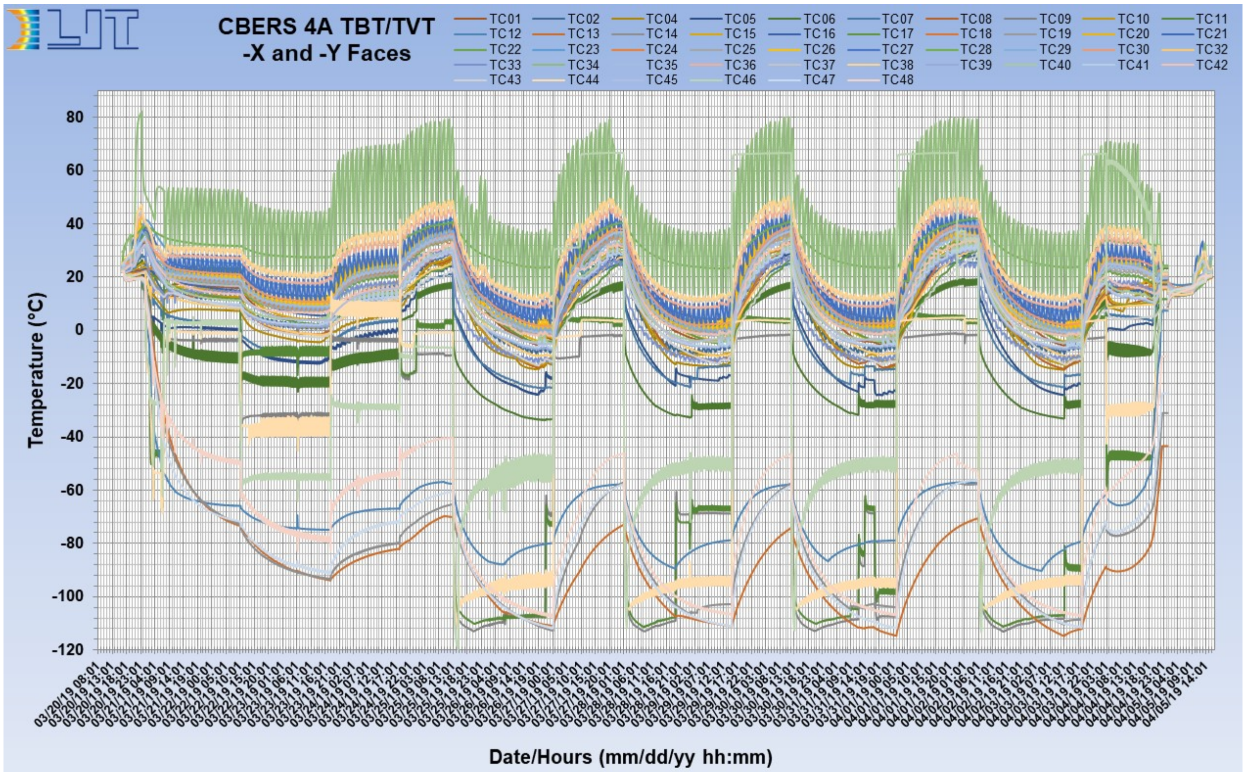

Fig. 10. -X and –Y Faces Temperature profile during TBT/TVT

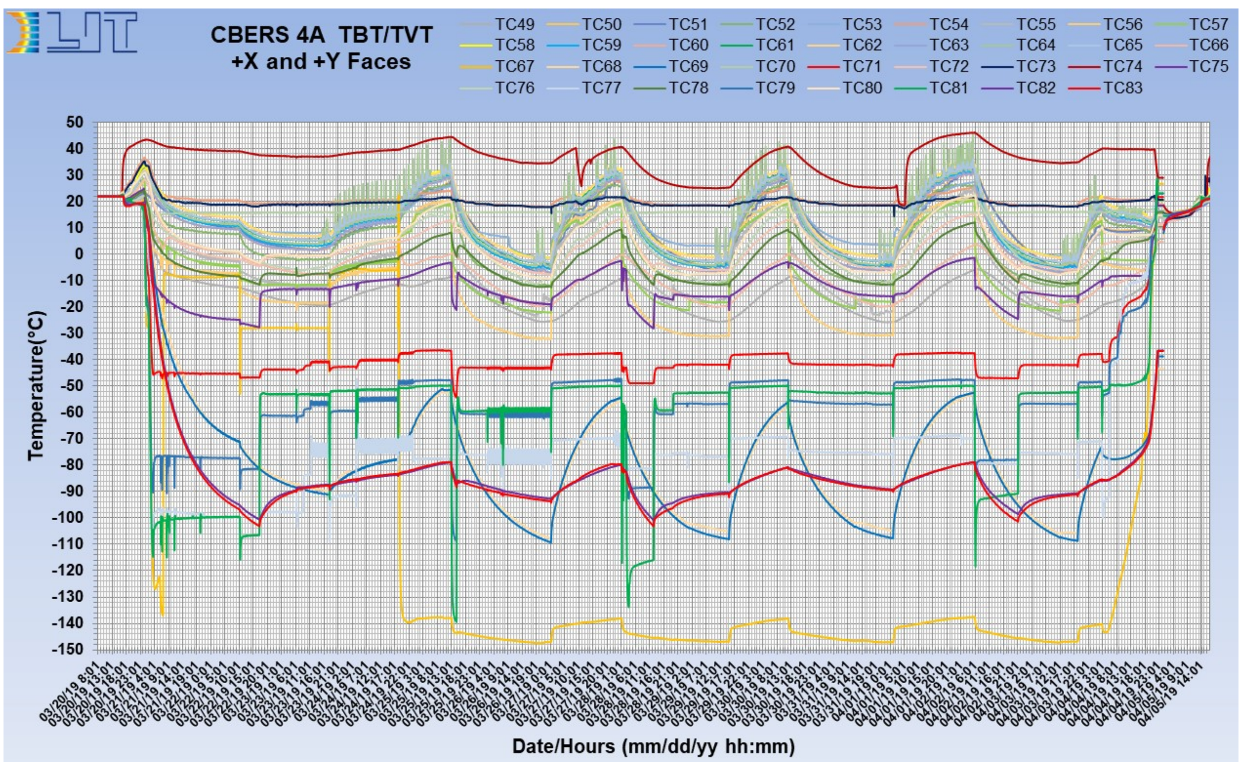

Fig. 1. +X and +Y Faces Temperature profile during TBT/TVT

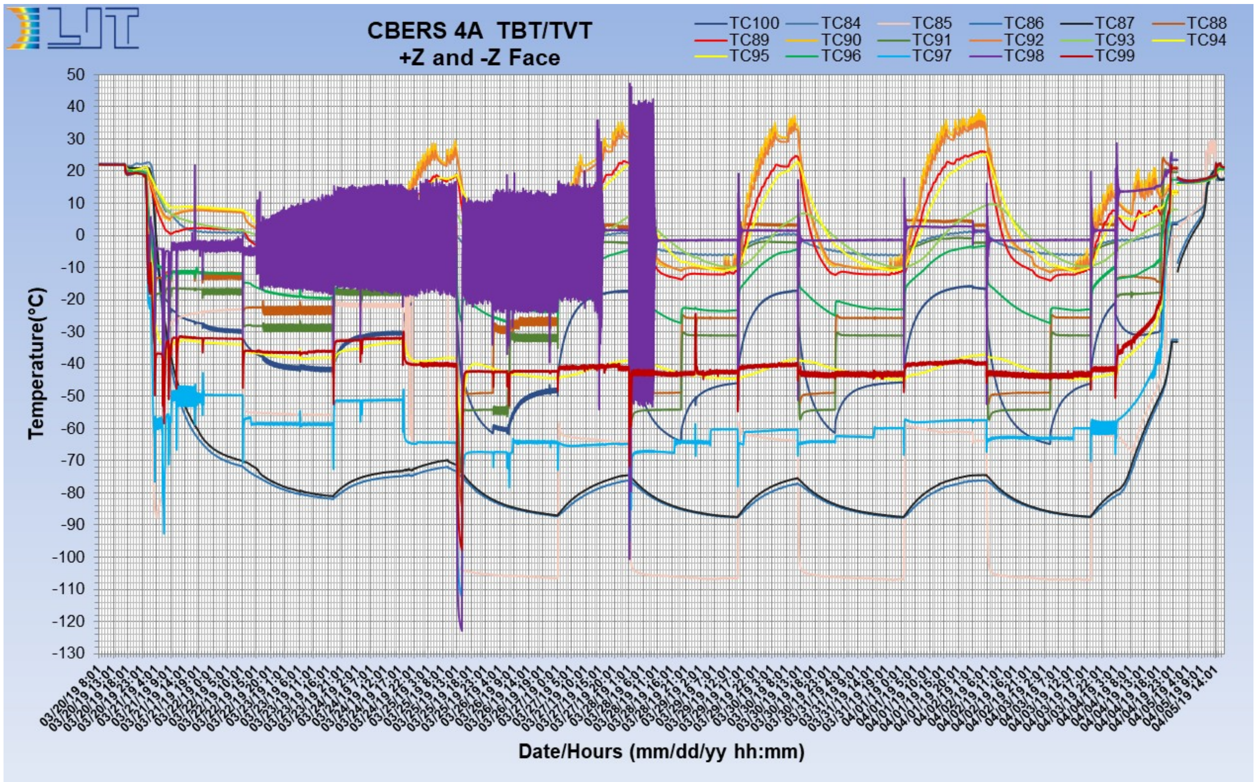

Fig. 12. +Z and -Z Faces Temperature profile during TBT/TVT

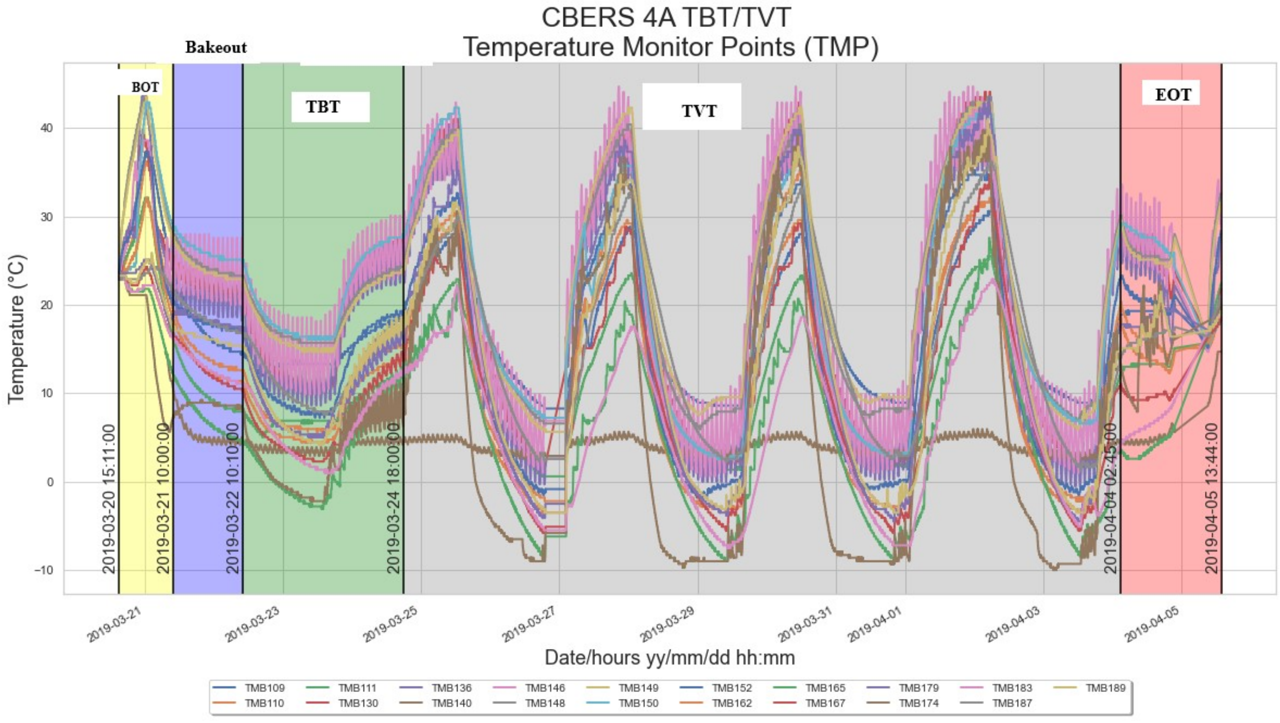

Fig. 13. TMP data during TBT/TVT

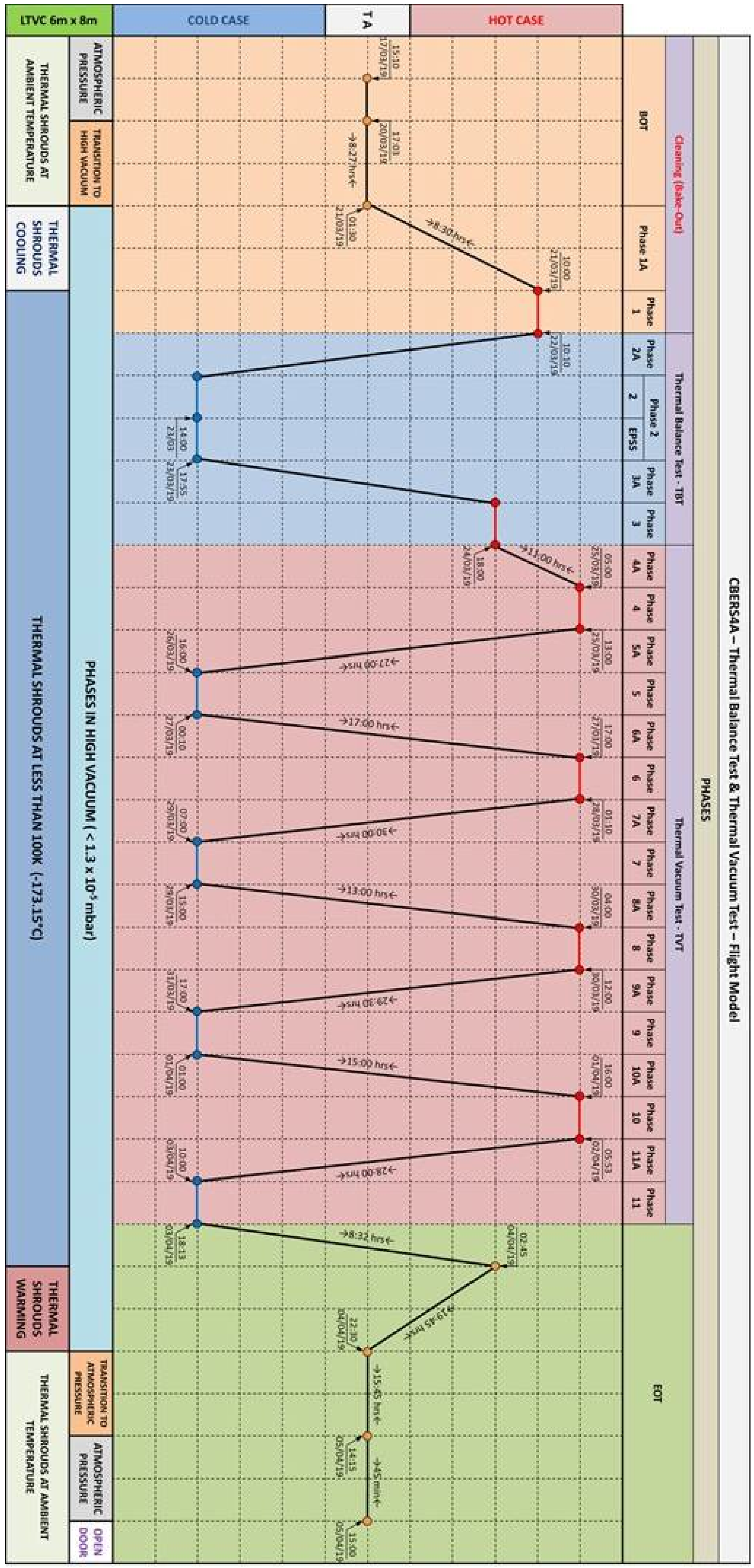

Fig. 14. Test sequence