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Abbreviated terms

ADCS	Attitude Determination and Control System
AP	Argument of Perigee
AR	Acceptance Review
COMM	Communication subsystem
CONF	Configuration
DT	Deployment Team
EM	Engineering Model
EPS	Electrical Power System
ESA	European Space Agency
FM	Flight Model
FRR	Flight Readiness Review
GS	Ground Station
IADC	Inter-agency space debris coordination committee
LEO	Low Earth Orbit
MA	Mission Analysis
MDR	Mission Definition Review
PDR	Preliminary Design Review
SC	Spacecraft
SKA	Studenckie Koło Astronautyczne (Students' Space Association)
STM	Structural-Thermal Model
SW	Software
TBC	To Be Continued
TBD	To Be Defined
TCS	Thermal Control System
TVAC	Thermal Vacuum Cycling test
TVC	Thermal Vacuum Chamber
WUT	Warsaw University of Technology

1 SCOPE

1.1 OBJECTIVE

This document contains the test plan for PW-Sat2 satellite hardware, including thermal tests of integrated satellite and functional test of the integrated satellite – STM and FM. The main purpose of the satellite's test is to validate the design and prepare it to launch on board Falcon 9 rocket.

1.2 SCOPE

The PW-Sta2 satellite test models consists of:

- fully integrated PW-Sat2
- Structural-Thermal Model of PW-Sat2 (STM)

2 Model Description

2.1 Satellite

2.1.1 Fully integrated satellite

PW-Sat2 is a 2U (10x10x20 cm, 2.66 kg) CubeSat satellite with 2 main deployable subsystems: SAIL and SADS. This document is focused on presenting the general concept of the thermal tests' plan of the satellite as well as its thermal management in the space-like environment to properly correlate the thermal model. The most important objective of the tests is to verify, if the most critical components are maintained within their temperature limits.

PW-Sat2's general design is presented in the Figure 1-1.

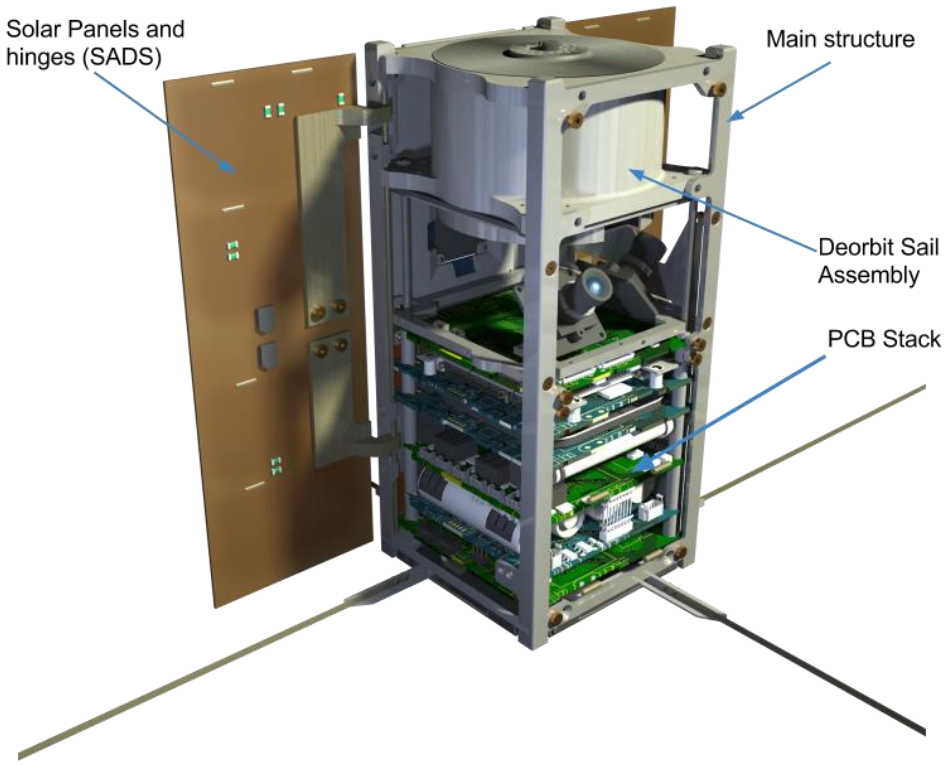

Figure 2-1 PW-Sat2 satellite's main subsystems configuration (outside walls and solar panels removed)

The satellite can be divided into several modules:

- Structure – two 2U X+, X- frames and Z- frame which is a base mount for PCB Stack
- SAIL – consists of: sail, sail's container and SRM (Sail Release Mechanism) located under the container (described in section 1.2)
- SS – Secondary Structure which serves both as an additional structural strengthening and cameras mount
- PCB Stack – consists of every piece of electronic equipment
- SADS and Solar Panels – one of the deployable mechanisms; Solar Arrays Deployable System consists of hinges on both Y sides of the satellite and Solar Panels connected to them (described in section 1.3)
- SARM – Solar Arrays Release Mechanism is not shown in the Figure 1-1; subsystem responsible for deploying the Solar Panels in the right time
- SunS – Sun Sensor is not shown in the Figure 1-1; one of the experiments of PW-Sat2 mission

Primary structure is also an interface for many elements on the satellite, such as PCB stack (as shown in figure 2-2), SARM, 1U Solar Panels, Sun Sensor, Sail's container and Secondary Structure. Structure positions them and is a stiff support for elements. Main structure is a mounting for kill switches and their rods as well.

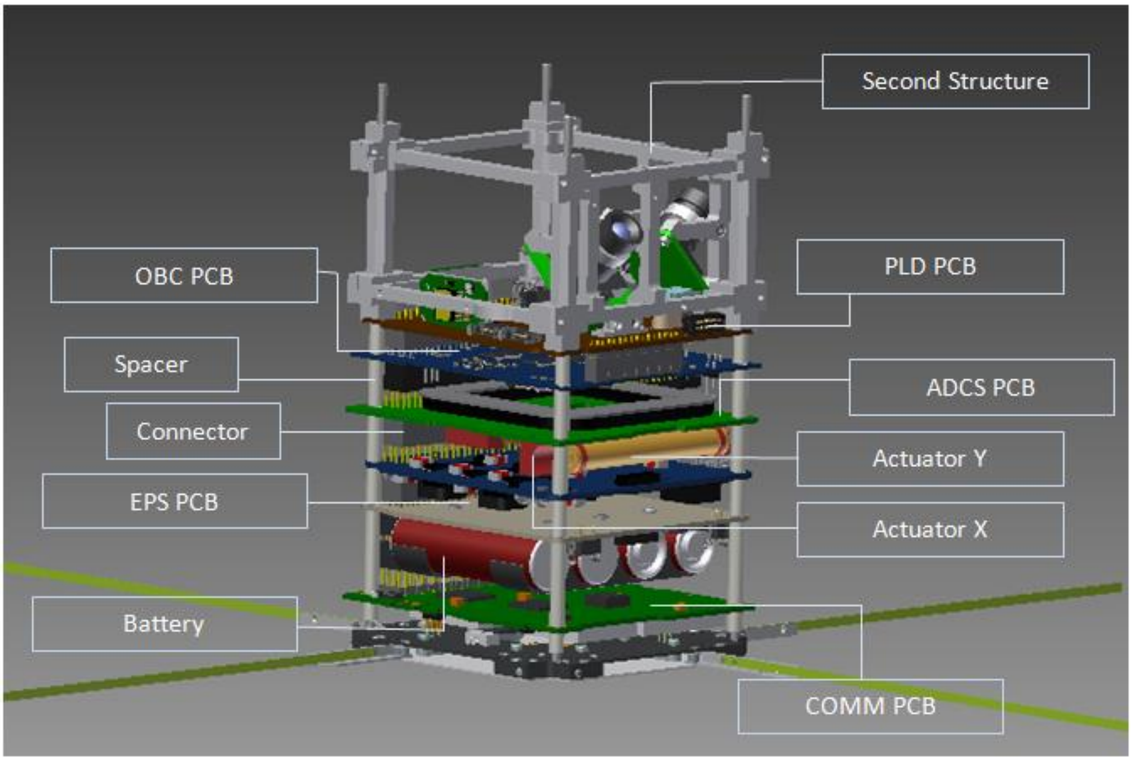

Figure 2-2 Assembly of PCB stack

2.1.2 Structural-Thermal Model of PW-Sat2 (STM)

STM Model will be prepared for preliminary test of PW-Sat2 components. From thermal point of view will be as close as possible to the Flight Model (FM) – main structure will be same as in FM, other components like PCBs or solar cells will be substituted by FR4 boards or surface finish, that can successfully imitate the thermo-optical properties of the FM. Heaters will be mounted in hot points of the satellite to simulate real heat dissipation on the satellite. Electronics will be substituted by dummy electronics boards with exact mass equivalent (no electronics/software tests can be performed on STM Model). Deployable Solar Arrays will be replaced by its geometrical and mass equivalent.

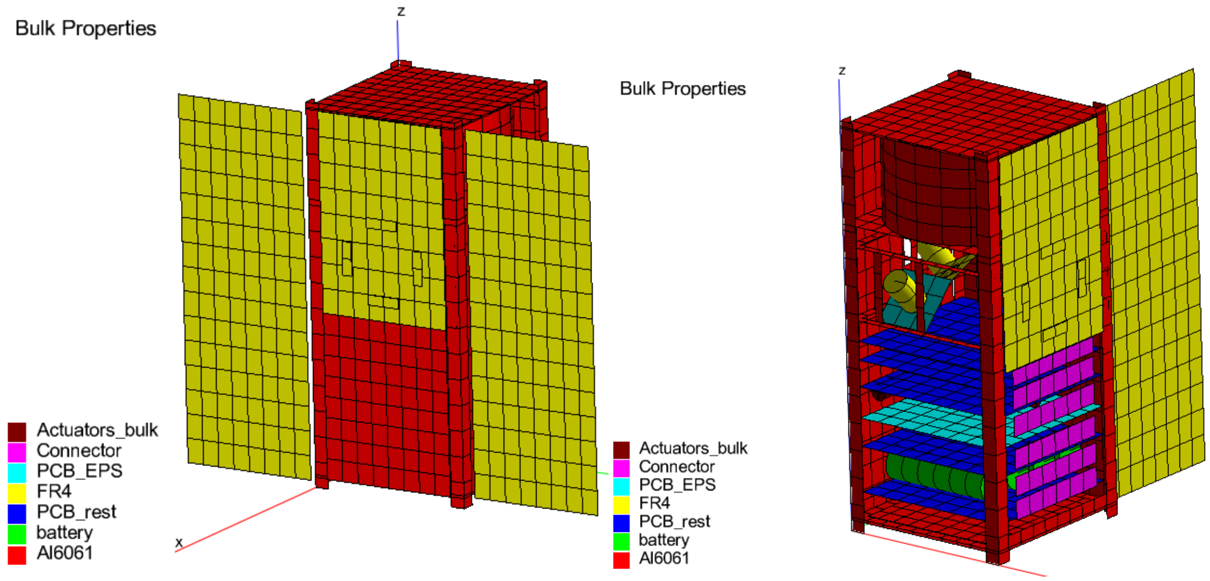

Figure 2-3 Simplified STM describing material selection of every component

Table 2-1 Material selection for each component

Component	Material	Component	Material
Structure	Aluminum 7075	CAM2	FR-4
Support Rod	Stainless Steel	PAYLOAD PCB	FR-4
Spacer	Aluminum 7075	EPS PCB	FR-4
Solar panel	FR-4	Batteries	Li-ion
OBC PCB	FR-4	Antenna	Aluminum/FR-4
ADCS PCB	FR-4	COMM PCB	FR-4
Actuator[1]	Ferrite	Connector	Polyester/Phosphor Bronze
Sun Sensor	FR-4	CAM1	FR-4

3 ENVIRONMENT

3.1 THERMAL VACUUM CYCLING TEST (TVAC)

According to the CubeSat Design Specification and QB50 document, PW-Sat2 functionality needs to be tested under the influence of the changing thermal environment under high quality vacuum. This is the general requirement for the CubeSats to verify their thermal design. Before and after the test, a full functional test of the satellite needs to be performed, and two tests during the thermal cycling – one for maximum temperature and one for minimum.

Table 3-1 Thermal vacuum cycling test specification

	Qualification	Acceptance	Protoflight
TVac test	Required	Not Required	Required
Min temperature	-20±2^{o}C		-20±2^{o}C
Max temperature	50±2^{o}C		50±2^{o}C
Temperature variation rate	≥1^{o}C/min		≥1^{o}C/min
Dwell time		1 hour at extreme temperatures	
Vacuum	10^{-5} mBar		10^{-5} mBar
Cycles	4		4

3.2 BAKE-OUT

As PW-Sat2 is launched on Falcon 9 rocket, it has to meet certain thermal requirements. The most important one is the total mass loss of the satellite must be below 1% when exposed to space environment and high temperature during launch phase, to not pollute other spacecraft. In order to qualify for the flight, a bake test-out needs to be performed to verify outgassing ratio. The total mass loss is determined by the difference in CubeSat mass during measurement before and after the test.

Table 3-2 Bake-out test specification

Characteristic		Qualification	Acceptance	Proto-flight
Test		Not required	Required	Required
Temperature			60 [C]	60 [C]
Pressure			< 5 x 10^{-5} [Torr]	< 5 x 10^{-5} [Torr]
Duration			24 [hours]	24 [hours]

4 TEST PHILOSOPHY

Due to the uncertainties of the thermal model design – lack of precise information about the components material composition, their thermal properties, as well as thermal interfaces across the structure – an STM thermal tests needs to be performed to imitate the final model of the satellite and determine the overall temperature distribution under certain thermal conditions as well as to validate and correlate the thermal mathematical model of PW-Sat2. This is necessary to help prepare a more precise and reliable analysis of the FM.

Another set of tests is related to general and launch provider requirements that needs to be met. In a second phase of test, the FM will be first tested in a TVAC to perform functional tests. The main reason is to verify, if no failures occurs under thermal stresses. Full functional test is performed before TVAC, two times during thermal cycling – one for maximal thermal plateau and one for minimal – and after the test.

Overall the thermal tests will be separated into two phases:

- Phase I –verification of the thermal design using STM under different thermal loads
- Phase II – TVAC and bake-out tests of the FM

4.1 SATELLITE TEST PLAN

The whole satellite will undergo TVAC and bake-out tests, with functional test described in chapter 5, before and after both tests.. On the Figure 4-1 test plan for both the STM and integrated satellite is shown.

First phase consists of TVC test, where the STM will be set in 3 different thermal conditions (cases) under which a map of temperatures will be measured with the use of approximately 10~15 temperature sensors across the whole model (depending on the TVC capabilities). Based on those results, a thermal mathematical model will be correlated and new set of analysis performed to provide more reliable results. In order to provide a high quality results, the model will be suspended inside TVC on a very thin Kevlar cables to conductively insulate the STM from the TVC. No functional tests are performed during this phase.

Second phase consists of a set of tests of the FM to check its performance under thermal cycling stress with functional tests to verify its influence on the components. First, a Pre-TVAC functional test is performed to prepare a reference functionality of the satellite. During TVAC test, another set of functional tests is performed for the highest and lowest temperature plateaus. After the TVAC test, final functional tests are performed to verify the influence of thermal cycling on the components.

As a part of Phase II, a bake-out test is conducted as a launch provider requirement to verify, if the total mass loss is below 1% (TML<1%), according to standards (QB 50 System Requirements and Recommendations). Pre TVAC and post TVAC test required before and after thermal vacuum tests. The mass measurement device must be able to determine a mass-change, if it occurs, of < 0.1%.

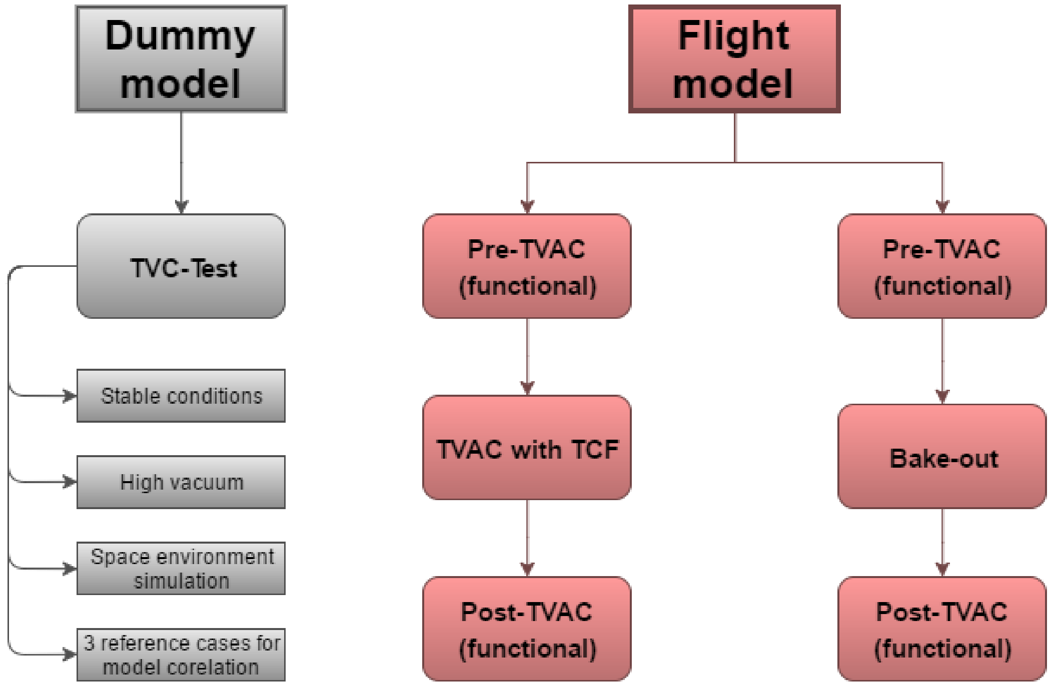

Figure 4-1 Graph of the thermal tests to be performed (Dummy model is for STM)

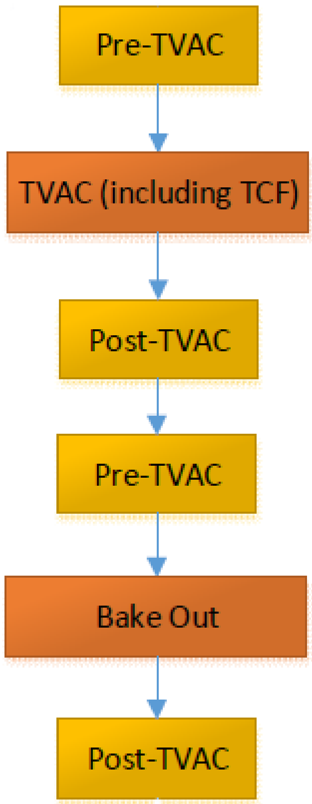

Figure 4-2 Flow-chart of the second phase thermal tests (only)

5 FUNCTIONAL

5.1 FULL FUNCTIONAL TEST OF THE SATELLITE

According to the QB50 System Requirements and Recommendations document, a full functional test of all possible components in the satellite needs to be performed to verify the performance under thermal loads. Full list elements to be tested is presented in a table below.

Table 5-1 List of steps to be performed during functional test

Subsystem	Test ID	Test/Verification Description
OBC	OBC01	Verify that EPS supplies power to OBC board(s).
	OBC02	Verify that OBC receives power and commands through umbilical connector.
	OBC03	Verify that OBC transmits data to COMM subsystem.
	OBC04	Verify that OBC receives and stores in the memory data from COMM subsystem.
	OBC05	Verify that OBC can access and read data stored in memory.
	OBC06	Verify that OBC can read, store and transmit toCOMMsubsystem, data coming from sensors or subsystems boarded.
	OBC07	Verify that OBC sends activation command to deployables (such as booms, antennas, panels etc.) not before than 30 minutes after deployment switches activation.
	OBC08	Verify that OBC activates RF transmitters not before than 30 minutes after deployment switches activation.
COMM	COM01	Verify antenna connection.
	COM02	Verify that antennas receive signals from COMM subsystem.
	COM03	Verify that antennas transmits signals to COMM subsystem.
	COM04	Verify that antennas receives signals from external sources.
	COM05	Verify that antennas transmits signals to external receivers.
	COM06	Verify power supplying to the transceiver.
	COM07	Verify that COMM subsystem receives signals from OBC.
	COM08	Verify that COMM subsystem transmits signals to OBC.

	COM09	Verify that transceiver decodes the received signals into the expected data format.
	COM10	Verify that transceiver encodes the received signals from OBC into the expected data format.
	COM11	Verify transceiver modulation.
	COM12	Verify the capability to shut down the transmitter after receiving the transmitter shutdown command.
	COM13	Verify that a power reboot doesnt re-enable the transmitter after receiving the shutdown command.
	COM14	Verify the capability to re-enable the transmitter after receiving a specific enabling command.
	COM15	Verify that the transceiver operates in the expected (and officially assigned) frequencies both in Tx and Rx.
	COM16	Verify beacon timing and transmitted data.
EPS	EPS01	Verify battery voltage both with GSE and by telemetry data reading.
	EPS02	Verify battery temperature readings by telemetry.
	EPS03	Verify 3.3V regulator output voltage level.
	EPS04	Verify 5V regulator output voltage level.
ADCS	ADCS01	Verify that power is supplied to ADCS board(s).
	ADCS02	Verify capability to enable/disable power to ADCS.
	ADCS03	Verify that power is supplied to magneto-torquers.
	ADCS04	Verify the capability to enable/disable power to coils.
	ADCS05	Verify that ADCS sensors data are consistent (gyroscopes, accelerometers, etc).
PLD	PLD01	Verify power supplying to the payload.
	PLD02	Verify that payload unit receives signals from OBC.
	PLD03	Verify that payload unit sends data to OBC in the expected format with expected content.
	PLD04	Verify that OBC is capable to enable/disable power to the payload unit.

6 FACILITIES

6.1 TVAC CHAMBER

All the tests described in this document need to be performed in a thermal vacuum chamber, capable of reaching high vacuum of a pressure up to 5×10^{-5} mBar, and the temperature up to -150°C to simulate space environment. Moreover, the integration of the satellite and preparation for the test needs to be performed in a cleanroom in order to not contaminate the surfaces and decrease the performance of the vacuum.

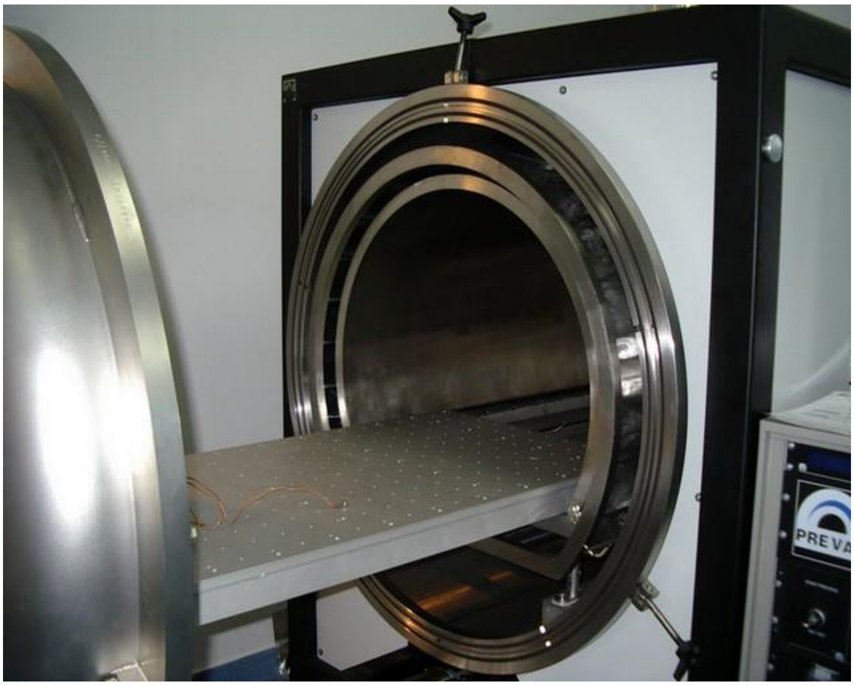

Figure 6-1 An example of a thermal vacuum chamber in CBK PAN

For the tests of the STM model to correlate the thermal mathematical model, a set of Kapton heaters will be used to imitate the heat dissipation of the electrical components and the Sun heat source by mounting additional heaters on the front and solar panels.

Figure 6-2 Kapton heater used to imitate heat source and dissipation