Flatsat Semester Report

Abstract

The following report details the work performed in the context of a semester project to create a flatsat for the EPFL spacecraft team. It describes all aspects of the classical system engineering approach, starting out with defining the requirements of the test bench. It also includes the creation of a testing plan, the design for the flatsat as well as the manufacturing and a description of the first tests that were performed. The flatsat is the first piece of hardware needed for the validation and verification flow outlined for the CHESS mission of the EPFL spacecraft team. It allows for a first verification of all the electrical and information interfaces of the satellite. Additionally it can later be used to conduct end-to-end mission simulations to verify the operational concept of the cubesat.

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Glossary

EPS: Electrical power system
ADCS: Attitude determination and control system
OBC: On board computer
UHF: Ultra high frequency
CHESS: Constellation of high-performance exospheric science satellites
PCDU: Power control and distribution unit
SDR: Software defined radio
GNSS: Global navigation satellite system
UART: Universal Asynchronous Receiver/Transmitter

1 Introduction

A flatsat is a vital component in the development of most spacecraft. It consists of the avionics of the satellite, which are laid out flat on a plate. This allows for easy access to each component in order to do changes, repairs or reconfigurations. The tests conducted on a flatsat are usually focused on verifying the electrical and information interfaces of the spacecraft. However, it can also be used as an end-to-end simulator of the mission operation concept of a mission. In that scenario, all subsystems of the flatsat are representative of the final satellite design. The goal is to make the flight software believe that the flatsat is actually in space, conducting its mission. For that purpose the sensor data needs to be emulated. This allows then also to train satellite operators in the operation of the spacecraft both in nominal and non-nominal situations. This report however describes work that focuses on verifying electrical and information interfaces. The goal is to transform this first design into an operations simulator at a later stage. This was part of the considerations for this first version too.

The CHESS mission is lead by the EPFL spacecraft team. Its goal is to develop a Cubesat that flys in a sun-synchronous orbit. Two scientific instruments will be on board. The main payload is a mass spectrometer that measures the ion content of the exosphere. These measurements have not been done since the 1980's. Thus the instrument can provide data of better resolution. Additionally, it is interesting to compare the datasets and study the effect of climate change in the past 40 years. The second instrument on the CHESS mission is a GNSS receiver. This payload enhances the data gathered by the mass spectrometer, as it allows us to know the precise location and velocity at each measurement point.

The other subsystems that are present on the satellite are the electrical power system (EPS), the onboard computer (OBC), the attitude determination and control system (ADCS) as well as the UHF and X-band transceiver modules. The EPS, OBC and X-band systems are manufactured in-house whereas the ADCS and UHF modules are bought from a supplier.

As of writing the spacecraft has passed its preliminary design review. For the preparation of the critical design review the spacecraft team is getting support of the European Space Agency as a part of the Fly Your Satellite Design Booster program.

As the first engineering models of the different subsystems are available now, it was the perfect moment to start thinking about the flatsat. It marks the first step in the verification and validation process of the CHESS mission. This is the case as engineering models are cheaper and faster to obtain then qualification models used for the later stages of testing. Additionally, it is important to validate the electrical and information interfaces first as any issue detected during these tests might result in a redesign of the system. It is therefore best to detect any potential flaws as early as possible.

The following report will focus on the EPS, OBC, ADCS and UHF subsystems, as these are the modules for which the spacecraft team already has engineering models.

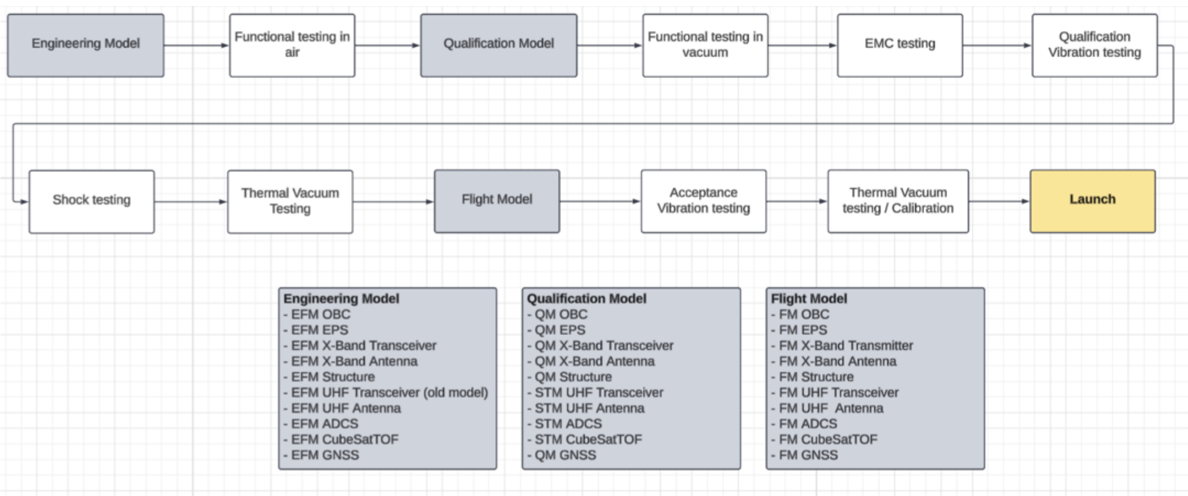

Figure 1.1: Validation and Verification process of the CHESS mission

2 Requirements

The first thing to do in the design process of the flatsat was the creation of the requirements for it. Initially it was unclear on how to derive or come up with the requirements for the test bench. However, a solution that worked well and made sense within the context of the mission was quickly found. The requirements for the CHESS mission are organized in a tree like manner. At the root of the tree are the mission level requirements. These are derived directly from the scientific goals of our payload and are formulated in a very general way. Based on this set of top level requirements, system requirements are derived for both the satellite and the ground segment. Based on that requirements for all the subsystems are then derived. These are then further split up into requirements for each individual component.

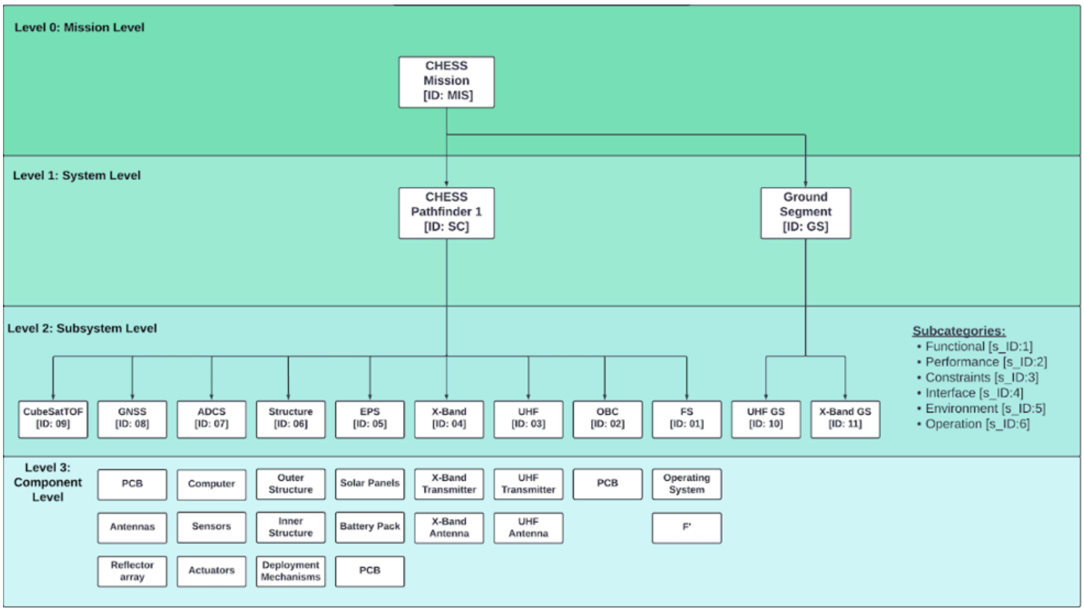

Figure 2.1: Requirement structure of the CHESS mission

The requirements for the flatsat can be found in the appendix to this report. In most cases, they were derived from the subsystem level requirements of the CHESS mission. The primary task of the flatsat is the verification of requirements from other subsystems. Therefore the wording in the flatsat requirements is in a lot of cases: "The flatsat shall allow to verify that ...". The requirements derived in that way can be grouped into two distinct themes. These groups consist of OBC- as well as EPS themed requirements. This makes sense as the main goal of the flatsat is to verify electrical and information interfaces, which are covered by these two subsystems. The OBC requirements consist of requirements that focus on the ability of the OBC to execute commands received from the ground. Additionally, it is also the task of the OBC to collect and store housekeeping data of the other subsystems. This helps to ensure that all the modules on the flatsat are working properly.
The EPS requirements for the flatsat focus on the verification of the EPS system itself. Further, it is also the goal to verify the distribution of power within the satellite with the flatsat.
Another set of requirements is specifically made to define the development of the flatsat. It contains requirements on the modules mounted to the flatsat and the software to be

used. Additionally, it is required that the flatsat can operate at room temperature and room pressure.
The last set of requirements is directly sourced from the system level requirements of the CHESS satellite. This was done when a specific high-level requirement was not adequately covered by a subsystem requirement. Additionally, some requirements were included that focus on the validation of the whole mission. The flatsat shall be able to perform end-to-end mission simulations and requirements need to be put into place in order to ensure this capability.

3 Testing plan

The next step in the design process was the creation of tests that would allow the flatsat requirements to be verified. The testing plan can be found in the appendix to this report. The testing plan consists of five distinct tests. They are designed to be executed in their order in the testing plan. This is because the basic functionality tests do not only verify the functionality of the systems on the satellite but also for the flatsat itself. Therefore, they should be conducted before the other tests. The different tasks within one test can also be completed in multiple different tests. However, the order of their execution should match the order described in the testing plan. Every engineering module is tested extensively in isolation before putting it on the flatsat

The first test focuses on verifying the functionality of the EPS. The most important item in this test is to verify that the EPS delivers the correct amount of voltage to each subsystem. If an incorrect voltage were to be be delivered, the corresponding subsystem could be damaged. The rest of the tasks focus more on the individual capabilities of the EPS itself. Once we know that the modules receive the correct amount of power, we can focus on making sure that they are working properly. By collecting the housekeeping data of each module in the OBC, we verify that capability of the computer. Additionally, by inspecting the housekeeping data we get information of the health of each subsystem. If something is not properly working the housekeeping data might contain the answer as to why.

Test 3 focuses more on the individual capabilities of the OBC. The goal of the test is to establish a command pipeline between the OBC and the UHF antenna that is in turn connected to a laptop. Then a command could be sent that updates the computer's software and changes it's memory. This would be a first step in the direction of a test that focuses on the operational aspects of the satellite.

Test 4 hones in the testing even more on these operational aspects. It would make use of the Digital Twin of our satellite that is developed in-house. This software would be used to simulate in-orbit conditions for our cubesat. Like this We can simulate the amount of power that our solar panels generate and also possible communication windows. The goal of the test is to verify that the satellite is power positive, meaning that it is able to fully charge its batteries when it facing the sun.

Test 5 would be to validate the whole operational concept of the mission. The actual flight software should run on the OBC as it would in space. This requires that all of the sensors and actuators of the satellite are fully emulated. In the future this platform would also allow ground operators to train with a representative model of the satellite. It would even be possible to interject failures in the satellite and train the operators how to respond to them.

What I noticed while writing the testing plan is that the hardware that is required in order to complete a test increases with the complexity of the test. Therefore, I proposed to split the development of the flatsat into three distinct phases. Phase 1 focuses on relatively simple tasks that can easily be completed just by connecting the different subsystems and powering them on. It includes the above mentioned tests 1 to 3. Phase 2 consists of test 4. It would add the Digital Twin and some supporting electronics hardware to the flatsat. Its main goal is to verify the capabilities of the satellite over multiple orbits. Phase 3 is best described as the phase where the flatsat stops being used to verify single requirements but is instead used to validate the whole mission. Everything exposed to the flight software should be entirely representative of in-orbit conditions.

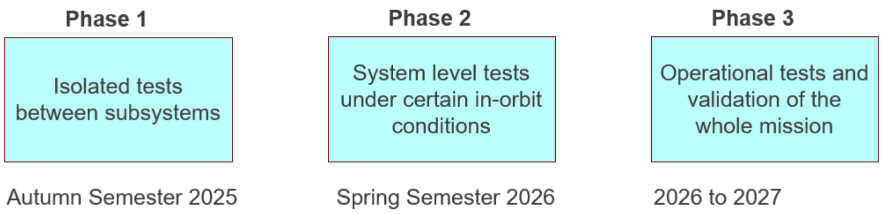

Figure 3.1: The three development phases of the flatsat and their timelines

4 Design

Writing the testing plan helped a lot during the design phase of the project. Specifically the segmentation of the development into three different phases helped to clear up any confusion about which parts are included. Additionally, this approach allows us to start testing with the flatsat even while its later stages are still being developed. The following designs focus on phases 1 and 2.

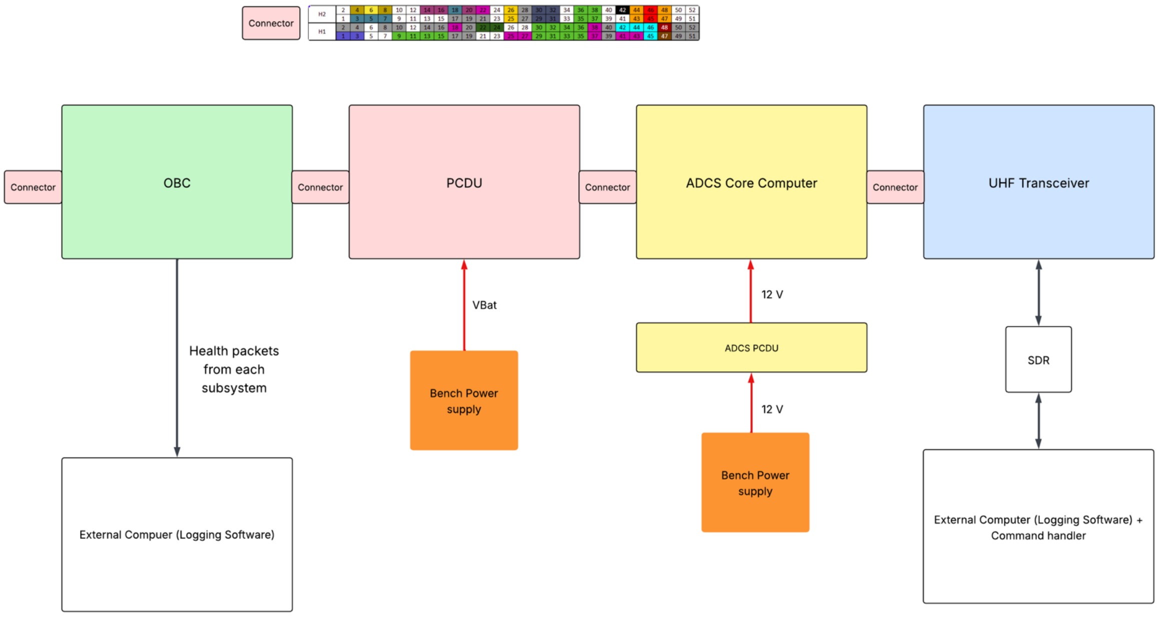

Figure 4.1: The design for phase 1 of the flatsat

The design includes engineering models of the OBC, EPS, ADCS and UHF subsystems. For the EPS only the Power control and distribution unit (PCDU) is used. The other part which consists of the battery pack is not yet used in this stage. This is both due to the fact that it is not needed for the tests of this phase and also that an Engineering model for the battery pack is not yet ready.
For the OBC the Monocan board that is developed in-house will be used. It is a replica of the current iteration of the flight computer. In contrast to that module it has a reduced set of redundancies. For the ADCS module the engineering model is supplied by 12 volts whereas the flight model of the ADCS will be supplied by 8.2 volts. For this reason an additional PCDU that belongs to the ADCS engineering model will be mounted on the flatsat.
Power will be supplied by two power bench supplies. One is connected to the ADCS PCDU and provides 12 volts. The other connects directly to the PCDU of the EPS. It supplies 8.2 volts and therefore simulates the power that the battery would supply on the real mission. The EPS then distributes the power to the OBC and to the UHF.
Both the information and the electrical interfaces on the cubesat use the PC104 protocol. Each subsystem has a set of 104 pins. In the satellite the modules will be stacked in such a way that all corresponding pins connect to each other. Since for the flatsat all the systems will be flat on a plate, the pins can not connect in that way. Instead, wires will be used to link the subsystems. In a later iteration the wires would be replaced by a printed circuit

board that would be a part of the baseplate of the flatsat. Each connector module in the diagram represents two sets of linked pins.
An external laptop would be connected to the OBC using its debug pin. With this interface test operators can inspect the memory of the OBC and observe housekeeping data that is sent from other subsystems. Another external laptop is connected to the UHF over a software defined radio (SDR). This device allows the simulation of the transmission of radio signals over long distances. Therefore we can use the external laptop to send commands to the UHF transceiver in a way that is representative of the conditions in space.

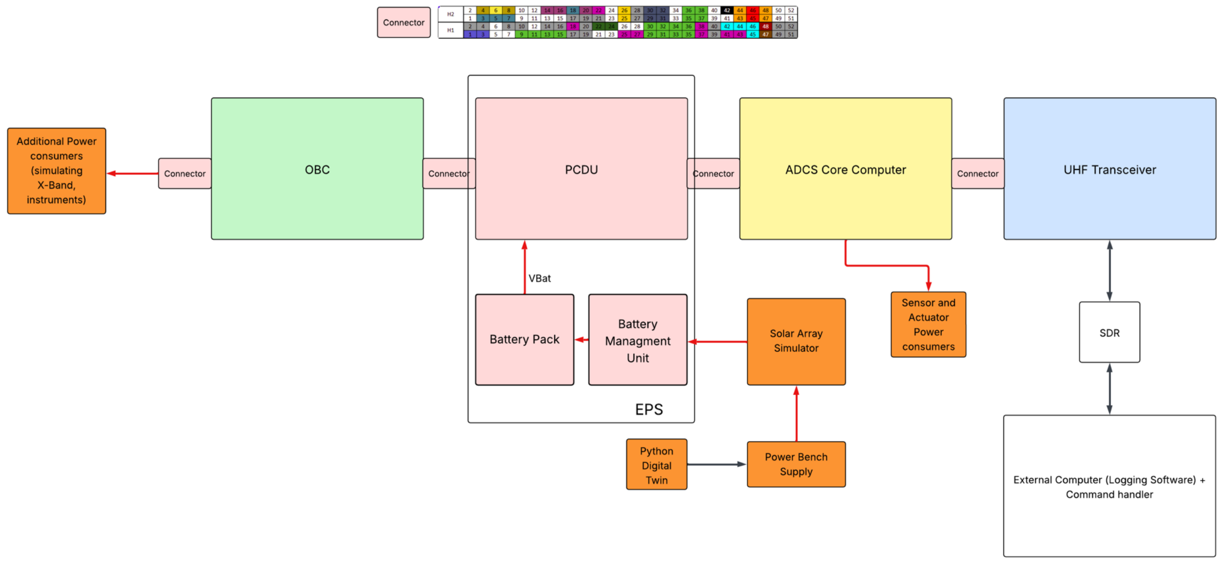

Figure 4.2: The design for phase 2 of the flatsat

The modules mounted in the second phase of the flatsat are the same as in phase 1. The one exception is that for the EPS now also the battery is mounted. Instead of connecting the external power supply to the PCDU, it now serves as a a representation of the solar arrays of the satellite. The amount of power that is supplied is controlled by the Digital Twin. The simulation of the satellite would run in real time during the tests and results would be directly used to change the state of the flatsat. The power bench supply is also connected to a solar array simulator that was developed in-house. This device transforms the voltage and current that the power supply provides into a form that would be provided by the solar arrays. The PCDU still provides power to the other subsystems. Building on phase 1, it now also provides power to the ADCS system. After testing the EPS in phase 1 and making sure that it works, we can now comfortably use it to power the expensive ADCS engineering model. As the ADCS engineering model needs to be supplied with 12 volts whereas the flight model will use 8.2 volts, the EPS is not designed to supply it. However, we can use a power output that is intended for the scientific instrument, which is powered by 12 volts.
As this version of the flatsat focuses more on the verification of the in-orbit performance of our system, we will also provide emulated data of the sensors and actuators of the ADCS. This is intended to be implement in our Digital Twin. Additionally, we would include systems that accurately draw the amount of power that subsystems that are not yet present on the flatsat would draw. The implementation of these power consumers would most likely be with resistors that could be turned on and off by the operator. In

a later stage they could be replaced by a more automated system that is connected to the Digital Twin directly. In this phase we would also use the Digital Twin to simulate communication passes of the satellite. This could be accomplished by having the software that sends commands to the satellite be adapted based on the current status of the satellite in the Digital Twin simulation.
After spending time on testing the subsystems in phase 1 and making sure that we could send and receive data over the UHF link, we would also get rid of the laptop that connected to the OBC in phase 1. The only way to communicate with the flatsat is by sending commands over the UHF link. Thus we transition to a more operational mode already in this stage of the development.

5 Testing

The stretch goal of having the first test done by this semester came into jeopardy when the OBC intended for the flatsat was damaged during manufacturing. The only remaining option to conduct a first test this semester was to use an older version of the OBC. The only communication interface that this version has is a UART connection. Since the ADCS is the only subsystem capable of transmitting using UART, the remaining time was focused on trying to establish a connection between the OBC and the ADCS. Unfortunately, the UART port on this new version of the OBC appeared to be broken as well. Thus, no test could be conducted. Nevertheless, the time invested in trying to achieve a first test result provided some valuable lessons. First, there was a large amount of time needed to set up and debug this test. It is likely that this time will be needed for every new module that is added to the flatsat. It is therefore highly likely that an approach where subsystems are added sequentially, and only after the previous subsystem is fully working, will yield results faster.
Second, it also showed that the teams that are testing the individual subsystems at the moment are not yet fully ready to have their system mounted on the flatsat, as a lot of isolated testing still needs to be conducted. It has therefore been decided to delay the manufacturing of the flatsat to a later point. When doing combined tests with different subsystems for now they will be connected with wires but not yet mounted at a fixed location.

6 Conclusion

The objective for this project was the design and creation of a flatsat for the spacecraft team at EPFL. Special care was put into following the traditional system engineering approach. At the start of the project the requirements were created. Based on them, a testing plan was produced that would allow to verify all the requirements. After that the flatsat that would enable to conduct the tests from the plan was designed. In multiple iterations the design was refined to produce the final result presented in this report. While we ultimately did not manage to conduct a first test during this semester, the work performed as a part of this project can be seen as foundational. The segmentation into 3 distinct development phases provides a clear path on how to upgrade the flatsat. Additionally, the testing plan then informs which tests to conduct in which development phase of the flatsat. Probably most importantly, people within the spacecraft team from all the different poles are starting to be aware of the existence of the flatsat and are thinking about how it might be useful for their specific subsystem.

Acknowledgements

I would like to thank Professor Emmanuelle David for supervising this semester project. I would also like to thank Ana Schwabedal and Alvaro Martinez for their technical support during the semester. Additionally I am extremely grateful for all the people that worked on the subsystems for the flatsat and rushed to make them ready before the deadline. Huge thanks also to Charles Rousset who spent a lot of time debugging the UART connection of the OBC.

Appendices

Requirements

Requirements ID	Title	Type	Requirement Text	Parent	Rationale	Success criterion - Rework is a bit needed	Verification Method	Date
Functional Requirements								
2_FSat_1_01	Power Distribution Verification	Functional	The Flatsat shall allow to verify that the EPS distributes power to every subsystem	2_EPS_1_01	EPS requirement that is planned to be verified on the Flatsat.	All subsystems are powered by EPS during functional test	Demonstration	11.03.2025
2_FSat_1_02	Power Storage Verification	Functional	The Flatsat shall allow to verify that the EPS stores power	2_EPS_1_02	EPS requirement that is planned to be verified on the Flatsat.	The EPS is working without external power input during functional test	Demonstration	11.03.2025
2_FSat_1_03	Power Evacuation Verification	Functional	The Flatsat shall allow to verify that the EPS evacuates the excess power out of the system	2_EPS_1_03	EPS requirement that is planned to be verified on the Flatsat.	When batteries are at 100%, the EPS doesn't send more current to charge them	Demonstration	11.03.2025
2_FSat_1_04	Power Generation Monitoring Verification	Functional	The Flatsat shall allow to verify that the EPS monitors the generated current and voltage	2_EPS_1_06	EPS requirement that is planned to be verified on the Flatsat.	We are able to measure the generated Current and Voltage with the EPS during functional test	Demonstration	11.03.2025
2_FSat_1_05	Power Demand Monitoring Verification	Functional	The Flatsat shall allow to verify that the EPS monitors the current and voltage drawn by each subsystem	2_EPS_1_07	EPS requirement that is planned to be verified on the Flatsat.	We are able to measure the drawn Current and Voltage with the EPS during functional test	Demonstration	11.03.2025
2_FSat_1_06	Health Monitoring Verification	Functional	The Flatsat shall allow to verify that the EPS, ADCS, OBC, UHF and X-Band subsystems generate House-Keeping (HK) data.	2_EPS_1_10, 02_ADCS_1_02, 2_OBC_1_02, 2_UHF_1_04, 2_XB_1_02	Subsystem requirements that are planned to be verified on the Flatsat.	Every subsystem from the parent requirements generates HK data during functional test	Demonstration	11.03.2025
2_FSat_1_07	Power Cutoff Verification	Functional	The Flatsat shall allow to verify that the EPS is able to cut the OBC's, ADCS', UHF's, X-Band's, GNSS' and CubeSatTOF's power supply	2_EPS_1_11	EPS requirement that is planned to be verified on the Flatsat.	The EPS can cut all of the power lines during functional test	Demonstration	11.03.2025
2_FSat_1_08	HK Data Collection Verification	Functional	Tha Flatsat shall allow to verify that the OBC collects the House-Keeping (HK) data from the other subsystems	2_OBC_1_03	OBC requirement that is planned to be verifies on Flatsat.	The OBC collects HK data from every subsystem during functional test	Demonstration	12.03.2025
2_FSat_1_09	Command Execution Verification	Functional	The Flatsat shall verify that the OBC executes commands received from the ground	2_OBC_1_04	OBC requirement that is planned to be verified on the Flatsat.	The commands received during the functional test are executed correctly by the OBC	Demonstration	12.03.2025
2_FSat_1_10	In-Orbit Software Updates Verification	Functional	The Flatsat shall allow to verify that the on-board software allows in-orbit changes of its configuration.	2_OBC_1_07	OBC requirement that is planned to be verified on the Flatsat.	The OBC's Software is successfully updated with an image provided by the communication protocols during functional	Demonstration	12.03.2025
2_FSat_1_11	OBC Reboot Verification	Functional	The Flatsat shall allow to verify that the OBC is able to reboot itself	2_OBC_1_09	OBC requirement that is planned to be verified on the Flatsat.	The OBC is rebooted during functional test and the satellite continues to work properly	Demonstration	12.03.2025
2_FSat_1_12	Subsystem Reboot Verification	Functional	The Flatsat shall allow to verify that the OBC is able to reboot all of the subsystems	2_OBC_1_10	OBC requirement that is planned to be verified on the Flatsat.	The OBC reboots all of the subsystems during functional test	Demonstration	12.03.2025
2_FSat_1_13	Maximum Power Production per orbit Verification	Functional	The Flatsat shall allow to verify that the EPS is able to provide an energy of 31 [Wh] over one orbit (95 mins)	2_EPS_2_02	EPS requirement that is planned to be verified on the Flatsat.	The EPS is able to sustain the desired energy during 95 minutes with a realistic power production	Test	13.03.2025
2_FSat_1_16	Maximum allowed regulated voltage Verification	Functional	The Flatsat shall allow to verify that the power line voltage is regulated at **+/- 5%**	2_EPS_2_05	EPS requirement that is planned to be verified on the Flatsat.	The measured voltage doesn't differ from the desired values during testing	Test	13.03.2025
2_FSat_1_17	Maximum allowed current Verification	Functional	The Flatsat shall allow to verify that the power line current is regulated at **+/- 5%**	2_EPS_2_06	EPS requirement that is planned to be verified on the Flatsat.	The measured current doesn't differ from the desired values during testing	Test	13.03.2025

2_FSat_1_18	Post-Ejection Verification	Functional	The Flatsat shall allow to verify that the EPS powers the CubeSat following ejection from the dispenser	2_EPS_6_01	EPS requirement that is planned to be verified on the Flatsat.	The EPS is turned on when the killswitches are released	Demonstration	13.03.2025
2_FSat_1_20	Operability Verification	Functional	The Flatsat shall allow to verify that the platform follows a pre-designed concept of operations and be able to change mode when required	0_MIS_15	Mission level requirement that the platform must be able to follow a set of commands to perform measurements and sustain the scientific tools	The platform has demonstrated its capability to reach all modes of operations before commision	Demonstration	13.03.2025
2_FSat_1_21	Power in Eclipse Verification	Functional	The Flatsat shall allow to verify that the CubeSat shall be able to operate without external power input for the duration of an eclipse	1_SC_1_03	Mission level requirement that the platform should keep operating under all orbit conditions.	All subsystems are powered during multiple simulated eclipses during functional test.	Demonstration	13.03.2025
2_FSat_1_22	Data Downlink Flow Verification	Functional	The Flatsat shall allow to verify that the CubeSat downlinks science and house keeping data in amateur frequencies to the Ground Segment	1_SC_1_04	Mission level requirement that the CubeSat must communicate its generated data to the ground	The telecom modules are transmitting data during a functional test under representative conditions	Demonstration	13.03.2025
2_FSat_1_23	Data Uplink Flow Verification	Functional	The Flatsat shall allow to verify that the CubeSat receives commands in amateur frequencies from the Ground Segment	1_SC_1_05	Mission level requirement that the CubeSat must be able to receive new commands from the operations team on the ground	The telecom modules are receiving data during a functional test under representative conditions.	Demonstration	13.03.2025
2_FSat_1_24	Beacon Signal Verification	Functional	The Flatsat shall allow to verify that the CubeSat has a beacon signal with a low data rate	1_SC_1_06	Mission level requirement based on ESA FYS requirement to be verified on Flatsat.	A beacon is transmitted during a representative functional test	Demonstration	13.03.2025
2_FSat_1_25	Autonomy Verification	Functional	The Flatsat shall allow to verify that the CubeSat operates autonomously when not in contact with the Ground Segment	1_SC_1_07	Mission level requirement that the CubeSat must also operate when not in contact with a groundstation.	Operations are carried out at all times during a functional test under representative conditions	Demonstration	13.03.2025
2_FSat_1_26	Attitude Control Verification	Functional	The Flatsat shall allow to verify that the CubeSat determines and controls its attitude	1_SC_1_08	Mission level rquirement since the CubeSat must do ground tracking to allow communication with the Ground Segment	The Spacecraft's attitude is controlled during a simulated functional test	Demonstration	13.03.2025
Interface Requirements								
2_FSat_2_01	Electrical interface Verification	Interface	All Flatsat subsystems shall receive and process electrical power from the EPS	2_OBC_4_01, 2_EPS_4_09, 02_ADCS_04_01, 2_UHF_4_01, 2_XB_4_01	/	Each subsystem receives the correct amount of power and is able to process it during a functional test.	Demonstration	13.03.2025
2_FSat_2_02	Electrical Power distribution Verification	Interface	The Flatsat EPS shall distribute power at the voltage level specified in the parent requirements to OBC, ADCS, UHF, X-Band, CubeSatTOF and GNSS.	2_EPS_4_01, 2_EPS_4_02, 2_EPS_4_02, 2_EPS_4_03, 2_EPS_4_04, 2_EPS_4_05, 2_EPS_4_06, 2_EPS_4_07				
2_FSat_2_03	Information exchange Verification	Interface	The Flatsat OBC shall be able to exchange commands with the EPS, ADCS, UHF, X-Band, GNSS and CubeSatTOF using the protocol from the parent requirements.	2_OBC_4_03, 2_OBC_4_04, 2_OBC_4_05, 2_OBC_4_06, 2_OBC_4_07, 2_OBC_4_08, 2_OBC_4_09, 2_OBC_4_10, 2_EPS_4_09				
Constraint Requirement								
2_FSat_3_01	EPS Inclusion	Constraint	The FlatSat shall contain an engineering model of the EPS	/	EPS functional requirements need to be verified by integrated and functional tests	Functional representation of the EPS is included in the design of the FlatSat	Review of Design	06.03.2025
2_FSat_3_02	ADCS Inclusion	Constraint	The FlatSat shall contain an engineering model of the ADCS	/	ADCS functional requirements need to be verified by integrated and functional tests	Functional representation of the ADCS is included in the design of the FlatSat	Review of Design	06.03.2025
2_FSat_3_03	OBC Inclusion	Constraint	The FlatSat shall contain an engineering model of the OBC	/	OBC functional requirements need to be verified by integrated and functional tests	Functional representation of the OBC is included in the design of the FlatSat	Review of Design	06.03.2025
2_FSat_3_04	UHF Inclusion	Constraint	The FlatSat shall contain an engineering model of the UHF antenna	/	UHF functional requirements need to be verified by integrated and functional tests	Functional representation of the UHF antenna is included in the design of the FlatSat	Review of Design	06.03.2025
2_FSat_3_05	X-Band Inclusion	Constraint	The FlatSat shall contain an engineering model of the X-band antenna	/	X-band functional requirements need to be verified by integrated and functional tests	Functional representation of the X-band antenna is included in the design of the	Review of Design	06.03.2025

2_FSat_3_06	**CubeSatTOF Inclusion**	Constraint	The FlatSat shall contain an engineering model of the CubeSatTOF instrument	/	Interaction between CubeSatTOF and satellite needs to be verified by integrated and functional tests	Functional representation of the CubeSatTOF is included in the design of the FlatSat	Review of Design	06.03.2025
2_FSat_3_07	**GNSS Inclusion**	Constraint	The FlatSat shall contain an engineering model of the GNSS Sensor	/	Interaction between GNSS and satellite needs to be verified by integrated and functional tests	Functional representation of the GNSS sensor is included in the design of the FlatSat	Review of Design	06.03.2025
2_FSat_3_08	**Flightsoftware**	Constraint	The CubeSat's flightsoftware shall run on the FlatSat OBC without modification	2_OBC_1_05	To guarantee that requirements verified on the FlatSat also hold for the satellite the software of the two systems must be identical.	Flightsoftware is run on the FlatSat during operations.	Demonstration	06.03.2025
Environment Requirements								
2_FSat_4_01	**Environment**	Environmental	The FlatSat shall work as intended at room temperature and room pressure.	/	The Flatsat will be stored and operated in a building. It should be compliant with all conditions encountered in that environment.	The FlatSat works as designed under room conditions.	Demonstration	06.03.2025
Operation Requirements								
2_FSat_5_01	**Power measurement**	Operational	The design of the FlatSat shall ensure that the Voltage and Ampere levels on cables between subsystems can be measured.	/	For debugging purposes the power levels for desired points in the satellite should be able to be measured.	The Design allows for the insertion of Voltage/Ampere meter between subsystems. Measurement has been demonstrated on the	Design Review / Demonstration	06.03.2025
2_FSat_5_02	**Full mission simulation**	Operational	The design of the Flatsat shall ensure that a full mission can be simulated with accurate behaviour in all subsystems.	/	To do full end to end testing it is essential that we can realistically make all the subsystems "believe" that they are in space and are interacting with the other systems.	Demonstrated 24 hour of continous operation of the platform during a functional test in representative mission conditions.	Demonstration	13.03.2025

Flatsat testing plan

Phase 1

Test 1: EPS functionality
Requirements: 2_FSat_1_01, 2_FSat_1_02, 2_FSat_1_03, 2_FSat_1_04, 2_FSat_1_05, 2_FSat_1_07, 2_FSat_1_16, 2_FSat_1_17, 2_FSat_2_02,

Firstly the Flatsat is turned on. Then the voltage and ampere which the EPS delivers to each subsystem is measured. This allows us to verify 2_FSat_1_01 and 2_FSat_2_02. The measured power is compared to the EPS's own measurements. If they match we have also verified requirement 2_FSat_1_05. After that the Flatsat power supply turns off. If everything continues to function as before, requirement 2_FSat_1_02 is verified. We also compare the provided power by the power supply to the EPS's measurements of that number. If they match throughout the test requirement 2_FSat_1_04 is verified. At the end the battery of the EPS gets fully charged and power continues to be supplied by the power supply. If the EPS evacuates this additional power as intended (not sure how this is done or how to measure it yet) then 2_FSat_1_03 is also verified. During the whole test the power line voltage and current is measured and compared to the expected number. If both values are between +/- 5 After that the EPS is commanded to cut off the power supply to each of the subsystems. If this is correctly executed, 2_FSat_1_07 is verified.

Test 2: Housekeeping
Requirements: 2_FSat_1_06, 2_FSat_1_08, 2_FSat_2_01

The Flatsat is turned on. The Flight Software is commanded to start running on the OBC. After some time we inspect the memory of the OBC, where we should find housekeeping data of each subsystem. If this is the case 2_FSat_1_06 and 2_FSat_1_08 are verified. Depending on the content of the Housekeeping data we can also verify if the subsystems correctly process the power delivered to them by the EPS. Therefore we can also verify 2_FSat_2_01

Test 3: OBC Functionality
Requirements: 2_FSat_1_09, 2_FSat_1_10, 2_FSat_1_11, 2_FSat_1_12, 2_FSat_2_03

The Flatsat is turned on. A command is sent to the OBC either via the UHF antenna pipeline or directly from a separate computer. The command would be formulated in a way such that it has an impact on the OBC's memory. Should the expected change in memory be detected, 2_FSat_1_09 is verified. After that a command to update the OBC's software is sent, with the new software version being transmitted either over the UHF or directly from a separate computer. The new software version should be made in a way such that the previous command is changed. After the update is complete, we resend the previous command. If everything was successful, we should observe the expected different data in the OBC's memory and have verified 2_FSat_1_10. After that a command to reboot the OBC is sent. If the rebooting is detected (for example no more heartbeat), 2_FSat_1_11 is verified. After that sequentially commands to reboot each subsystem are sent. The reboot process of the subsystem should be observable in their housekeeping data. If this process works for each subsystem then 2_FSat_1_12 is verified. additionally we have also exchanged commands with each subsystem, therefore verifying 2_FSat_2_03

Phase 2

In this phase parts of the input to the Flatsat are no longer static but instead simulate in-orbit conditions. Specifically the power input in this phase should match the expected power input in-orbit. Currently it is planned to use our Digital Twin for that matter.

Test 4: EPS in-orbit performance
Requirements: 2_FSat_1_13, 2_FSat_1_18, 2_FSat_1_21
While the kill switches were not required for phase 1, they will be added in phase 2. The first test is to turn the flatsat on by releasing the kill switch. If that works as intended 2_FSat_1_18 is verified. After that the Digital Twin is used to simulate the power input that the satellite experiences in-orbit. This power is then also given as input to the EPS (probably with a programmable bench power supply). The EPS behaviour, especially the battery charge is observed. The subsystems draw power such that 31 Wh are provided to them in 95 minutes. Should all EPS systems still be working successfully after 1 orbit (probably should be more than 1 orbit) then 2_FSat_1_13 is verified. Since in that case the EPS has also survived the eclipse, 2_FSat_1_21 is verified too.

Phase 3

In this phase in addition to the power input that is simulated, also the ADCS sensor inputs and actuators are simulated. This will most likely be done with software from the ADCS provider.

Test 5: Full mission simulation
Requirements: 2_FSat_1_20, 2_FSat_1_22, 2_FSat_1_23, 2_FSat_1_24, 2_FSat_1_25, 2_FSat_1_26, 2_FSat_3_08, 2_FSat_5_02 The remaining requirements are all mission requirements. In order to verify them we need a full simulation of the mission with conditions being representative of in-orbit conditions. For this test the flight software will be run on the OBC without any modification, therefore verifying 2_FSat_3_08. All interactions with the Flatsat during this test are commands sent through the UHF pipeline with the timing being limited to communication windows. The ability to communicate and the power generation depend on the performance of the ADCS system. This allows us to verify 2_FSat_1_26, as a non-functional ADCS system would result in a detectable problem with the satellite. During this test the satellite would be commanded to change its mode. If this works as expected we have verified 2_FSat_1_20. Additionally we can verify the requirements linked to the UHF pipeline 2_FSat_1_22, 2_FSat_1_23, 2_FSat_1_24. We can do this by observing traffic through the UHF system. If not in a communication window, the satellite must work autonomously which verifies 2_FSat_1_25. The whole test is designed to verify 2_FSat_5_02 if executed.