This project was carried out by a student from École Polytechnique Fédérale de Lausanne, member of the EPFL Spacecraft Team as part of its CHESS mission, supported by the EPFL Space Center.

System Engineering a New CHESS

Abstract

This report is an attempt to kickstart the work of the team that will pick up the CHESS mission from the system engineering side. This has been a rocky year and unfortunately many people with a deep understanding of the mission will be less involved or leave the project the next academic semester as their studies come to an end, etc. The last job left to do is transfer their knowledge and organize the information left behind in the best possible way. A list of contacts is made available at the end of this report and is to be used without hesitation.

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1 Introduction

1.1 Project Framework

The CHESS mission "Constellation of High Energy Swiss Satellites" is the first project of the EST (EPFL Spacecraft Team). It is a MAKE project supervised by eSpace, EPFL Space Center and many other professors in their respective domains.

The main goal of the EST is to help educate a new generation of scientists and engineers by giving them a first insight into the space industry through a practical project. CHESS is thus carried out by students who build up knowledge little by little. The risks are inherently very high but work is overseen by very experienced partners throughout Switzerland, who previously flew successfully space missions. A list of our partners is available in Figure 1.1. Recently added to the list is EnduroSat, an aerospace manufacturer thriving in the CubeSat business, based in Sofia, Bulgaria. This is therefore a very multidisciplinary, and now international project.

Figure 1.1: Partners involved in the CHESS mission and their locations in Switzerland, except for EnduroSat, headquartered in Sofia, Bulgaria.

1.2 Mission Overview

In a nutshell, the aim of the CHESS mission [12] is to launch two 3U CubeSats into orbit by 2023 with the main goal of measuring the composition of the atmosphere, a hot topic given the current climate change. Two instruments, payloads, both experimental, were selected to this end. First, the CubeSatTOF developed by UniBe and Spacetek, a mass spectrometer that fits in 10x10x10 cm^3. Second, the GNSS receiver developed by ETHZ and u-blox, capable of greater precision, and much more than a classical receiver. In addition to these two payloads, CHESS will fly and test its own on board computer developed in collaboration between EPFL and HES-SO, the flight software will likely be provided by HE-ARC.

The role of the EST is to do its best in coordinating such a long term effort between its many partners and in doing so, confront its members to real life situations.

Given the high stakes of the mission, decisions must be taken so as to maximise mission success where possible. As a result it is sometimes hard to distinguish and prioritize the educational aspects of the project. Therefore, the EST has decided to adapt and organizational changes will take place starting from autumn 2021.

1.3 A Brief History Review

The EST and CHESS were initiated in 2019 by three EPFL students: Nicolas Martinod, Alfonso Villegas and Tristan Trébaol as a collaboration between Swiss universities and industry. Various iterations of the mission objectives took place, crafted to fit the funding conditions of the Swiss Space Office and designed with science relevant to potential sponsors. However, the Covid-19 crisis soon hit and funding options became even scarcer than before. As a result of further discussions with the Swiss Space Office the project was pushed in a new international direction, hence the new collaboration with EnduroSat. The Swiss Space Office now seems willing to fund our scientific instruments if funding for the platform is secured. This came at an ideological cost. Students are no longer building/assembling as much as the original project intended, partnerships have been dropped and a portion of the work that had been done so far is now no longer relevant to the mission but remains a great learning source for those interested.

Since the beginning of 2021, several changes took place for the mission which made it hard to advance steadily in all areas. The team is now documenting what are, hopefully, the last major design changes the mission will face. The payloads of the satellites have finally been fixed. The schedule of the mission was shifted and hopefully some of the students working on this today will still be at EPFL when it takes flight.

Note that the whole CubeSat industry is relatively new and a lot of companies are still developing or refining their modules. Therefore, they have not yet built up sufficient flight heritage to distinguish themselves in the industry. This is noticeable in the case of EnduroSat as well. They are extremely skilled and knowledgeable but beware of conflicting documentation or incomplete information. As a result, it is advised to test everything as much as reasonably possible. With mission design and planning, this is and will be the main job of the EST. Knowledge acquired during this testing will be essential when manipulating the flatsat, a broken down version of the satellite used for debug purposes.

1.4 Abbreviations

A lot of people in this industry are a bit too fond of abbreviations. Try not to use them too much when not necessary. Here's a list of some of the ones frequently encountered and that might appear in this report.

- CHESS: Constellation of High Energy Swiss Satellites
- MD: Mission Design
- LV: Launch Vehicle
- SE : Systems Engineering
- EOBC: On Board Computer made by EnduroSat
- EPS: Electrical Power System
- ADCS: Attitude Determination and Control System
- UHF: Ultra High Frequency transceiver

- Xband: X-band transmitter
- RA: Radio Amateur (professionals)
- GNSS: Multi-GNSS Receiver payload (also global navigation satellite system)
- TOF: CubeSatTOF mass spectrometer payload
- HOBC: On Board Computer made in House
- GS: Ground Station
- Reqs: Requirements
- ConOps: Concept of Operations
- AIT: Assembly, Integration and Testing
- SSO: Swiss Space Office
- ECSS: European Cooperation for Space Standardization

1.5 Credits and Report Outline

This semester, three students worked on some aspects of system engineering for the CHESS mission as part of a credited project. Three separate reports will thus be filed and this is just one of them. Reference to their work and that of other students will be made in this report. This work is also the result of many discussions with people within the team who I thank for their time and work for CHESS.

In Section 2 is provided a summary of systems engineering practices and how they apply to the CHESS project and mission. In Section 3 you will find my personal reflection on the work accomplished during my time at the EST. In Annex B you will find a list of contacts. Information presented in this report is also on the CHESS drive [3].

2 System Engineering

2.1 General

Systems engineering is an interdisciplinary field of engineering and engineering management that focuses on how to design, integrate, and manage complex systems over their life cycles [49]. In the aerospace industry, usually associated with high costs and inability to prototype rapidly, the default development cycle follows the V-model portrayed in Figure 2.1. The CHESS project follows this model at its own pace, adjusting as it goes. The system engineering pole has a deep understanding of the mission as a whole and serves as a bridge between management, the team and our partners.

The CHESS mission uses ECSS standards [19] as guidelines for its activities. Tools typically used are spreadsheets and diagrams (Lucidchart [31]). A push is being made towards a model based approach through Valispace [45] but it is still a long way to go before we have a reusable model. Currently only budgets and requirements are in it but ideally visualizations or mission scenario simulations could take place.

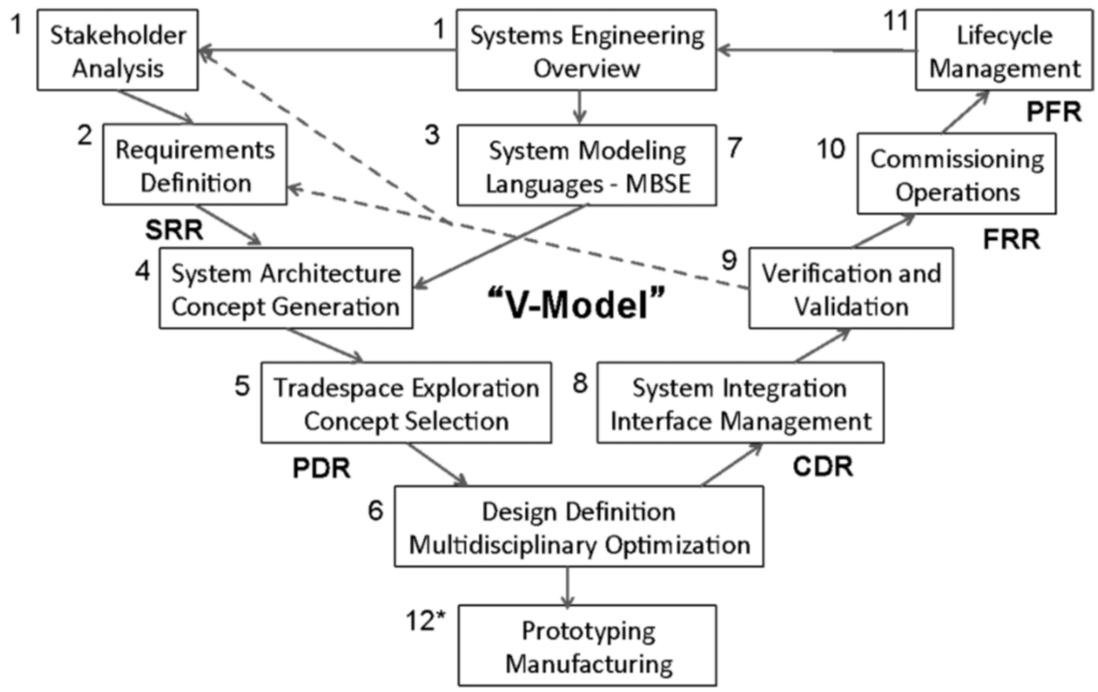


Figure 2.1: V-model development cycle in systems engineering [44] and stages where major reviews usually take place.

During this semester, due to changes triggered by the lack of funding, the left branch of the model in Figure 2.1 was revisited by the management and systems engineering team. We had to leave out the linear VHF-UHF transponder provided by the radio amateur community, planned as a payload since the early stages of the project. We reviewed and shared our requirements with EnduroSat. As a result of the platform modifications, the architecture of the satellite has changed as well. Trade-offs were made in the selection of subsystems needed for the mission. Planning work was done in terms of system interfacing and system integration, trying to anticipate potential bottlenecks.

On the other hand, our payloads are not operating at the same stage of the project as we are. Development has started but without funding they will remain stuck somewhere on the left branch of the V-model. The project is thus at very different stages in different areas and the EST acts as a buffer trying to make it all come together.

2.2 Stakeholders

The stakeholders of the CHESS mission are not limited to our partners in Figure 1.1. Any sponsor is a stakeholder. Anyone who could make use of the data the payloads gather is a stakeholder. Any person the mission can inspire is a stakeholder. This is a strong selling point for the mission and as system engineers work closely with management it is important to know who is impacted by the mission and be aware of the selling points and stakes behind decisions to be made. Reality is that each actor cannot be granted the same privileges. For example, the decision we took this semester about cutting out the radio amateur transponder ultimately impacted their entire community that planned to use our satellite for educational purposes. It also cut our ties with very knowledgeable people, on uneasy but seemingly good terms.

The human aspect of projects is not necessarily ingrained in us as engineering students and is hard to experience in the small time course projects usually take. However, as a system engineer, one needs to consider the human aspect of engineering projects early on. Failure to do so can result in lack of motivation, lack of trust, unnecessary mistakes, delays, partners falling out and in the worst case, project failure. This is probably the greatest difference one will experience being part of a long term MAKE project.

As a side note: although no contract has been signed yet (a memorandum of understanding between the CHESS Team and EnduroSat is on its way). With the switch to a commercial platform a lot of variables and responsibility have now been placed in the hands of EnduroSat. Bear in mind that some of the information we have access to with is shared under non-disclosure agreements.

2.3 Mission Design

2.3.1 Launch Vehicle

No technical change took place since last semester regarding the launch vehicle. Launch and early orbit operations (LEOP) have been accounted for in the ConOps already. The mission design pole is responsible for this part of the project and in collaboration with the system engineering pole will have to take care of the logistics behind their final choice. A more detailed description is available in [27]. The mission design pole also plans the orbits and space environment to expect, communication windows and end of life of the satellites.

This semester the team applied to an IAF competition that could win us a free launch on a Chinese rocket in 2022. This was obviously out of our timeline but we hope our project is of enough interest to the organizers that they invite us to Dubai to present CHESS at the International Astronautical Congress and open up our sponsoring options.

As a side note I suggest to keep looking into launch opportunities because during our last talk David Ryall [39] mentioned it is generally agreed that student projects fly for free as “there is always a free spot no one else will pay for in the pod so they might as well put it to use”. This is obviously to take with a grain of salt, especially since the elliptical orbit is very specific, but it might be worth investigating. A launch is costly (200’000 CHF per

3U satellite [25]), and it is always money the sponsoring team wouldn't have to fight for anymore.

2.3.2 Orbits

The CHESS mission plans a constellation of two satellites. One on a common circular sun-synchronous orbit at 550km and the other one on a rare elliptical orbit with perigee-apogee at 400-1000km. These two orbits are selected so that our measurements can track variations in time and space, respectively.

2.3.3 Radiation

A big question from last semester was regarding the differences between the two satellites. It is now safe to say the only difference might be in the shielding and not in the components. Typically EnduroSat protects its subsystems with 3mm of aluminium. If their own mission analysis finds we might be at risk of failure, they offer a better shielding consisting of 2mm aluminium + 1mm copper. No other changes have been anticipated so far but there's no guarantee they won't arise.

2.3.4 Communication Windows

This semester the mission design team compared results of different orbit propagators to validate their results [27]. Also impacted by some of the changes, they now need the updated specifications of the antennas and ground station to provide us with more accurate numbers. The major change concerns the Xband antenna, see Section 2.8.5.

2.4 Budgets

The budgets are an essential part of any space mission. What is intended here is not necessarily the financial budget but rather an engineering budget like SWaP-D (size, weight, power, data). It is very important for a system engineer to monitor those very carefully as the mission progresses. The mistake was made this semester of waiting too long to update the numbers we had before the switch to the EnduroSat platform and only then did we realize there was simply no space for the radio amateur payload. It is therefore crucial to have this information openly accessible and centralized, which is why time was spent setting it up on Valispace [45] and a backup spreadsheet is available on the CHESS SE drive [9] along with all other work done so far. In Figure A.1, in annex A, is a snippet of what one may find on Valispace when playing around with the options available. In Figure 2.2 is an overview of the values recorded on Valispace (data volume is omitted here for lack of proper estimates for all subsystems). For power budget details related to the different operational modes refer to the work of Celia Hermoso Diaz [17].

Notice that a margin has been allocated on top of all important numbers. A contingency/margin accounts for uncertainty or things otherwise hard to quantify such as cabling space, space needed to dissipate heat and an additional margin. Therefore, even if a number comes straight out of a datasheet, a contingency is attached to it. As the project progresses and certainty starts to take place, these can be refined and shrunk but it could be a costly mistake to start without them. As per constraint of the launch contractor the satellite's mass shall not exceed 5kg [10]. Before EnduroSat provides us their platform, the mechanical team shall ensure that the CAD model fits the requirements of the pod described in [27].

Subsystem	Size				Weight		Power (in most consuming mode)			
	Height [mm]		Width [mm]	Length [mm]	Mass [kg]		Average [W]		Peak [W]	
EOBC (no GNSS)	14.4	5%	89.0	93.9	0.130	5%	0.64	inc.	0.73	inc.
EPS	70	5%	90.2	95.7	1.050	5%	0.07	inc.	0.07	inc.
ADCS	75	5%	90.0	96.0	0.554	5%	1.02	inc.	4.25	inc.
UHF	11	5%	89.0	95.0	0.090	5%	2.64	inc.	2.64	inc.
XBand	22.5	5%	90.2	95.9	0.275	5%	6.20	inc.	9.00	inc.
TOF	100	8%	90.2	95.9	1.000	10%	7.06	inc.	9.00	inc.
GNSS	25	8%	89.0	95.0	0.150	20%	0.20	inc.	1.00	inc.
HOBC	15	8%								
STRUCT	340.5	-3%	100.0	100.0	0.340	5%	1.00	inc.	2.00	inc.
ENV Nav Satellites	N/A		N/A	N/A	N/A		N/A		N/A	
GS - Human - Stakeholders	N/A		N/A	N/A	N/A		N/A		N/A	
Total	353.745	mm			3.841	kg	OPERATION MODE DEPENDENT			
	CAREFUL				SEEMS FINE		RECAP TABLE SEEMS FINE			

Figure 2.2: High level SWaP (size, weight and power) budget preview. (For details about HOBC, see Section 2.8.8)

2.5 Timeline

In the industry, a few important reviews have been defined as milestones for space missions. Following the procedure established in the NASA handbook [38] should set the project on a good trajectory. The project phases are portrayed in Figure 2.3. Each of these phases is usually concluded by a review attended by the various stakeholders. CHESS passed two main reviews so far: PRR [10] (similar to MCR) and SRR [11], see Figure 2.4. The project is running at very different paces across the board. The platform can be provided by EnduroSat within 6 months. The CubeSatTOF, see Section 2.8.7, is still awaiting funding from the SSO that we can receive only once funding for the platform is secured. From there it will take a year to build the payload. The GNSS, see Section 2.8.6, seems to be advancing at steady pace and expected to be ready by the end of 2022. The HOBC, see Section 2.8.8, has just received news that we should be able to fly it. Although development was already on its way, the plans have changed and it is unclear how long is needed to have it ready. The EST is about to receive the last batch of modules to complete a functional flatsat. Before that, each pole will test the subsystems separately.

Phase		Purpose	Typical Outcomes
Pre-Formulation	**Pre-Phase A** Concept Studies	To produce a broad spectrum of ideas and alternatives for missions from which new programs/projects can be selected. Determine feasibility of desired system, develop mission concepts, draft system-level requirements, assess performance, cost, and schedule feasibility; identify potential technology needs, and scope.	Feasible system concepts in the form of simulations, analysis, study reports, models, and mock-ups
Formulation	**Phase A** Concept and Technology Development	To determine the feasibility and desirability of a suggested new system and establish an initial baseline compatibility with NASA's strategic plans. Develop final mission concept, system-level requirements, needed system technology developments, and program/project technical management plans.	System concept definition in the form of simulations, analysis, engineering models and mock-ups, and trade study definition
	Phase B Preliminary Design and Technology Completion	To define the project in enough detail to establish an initial baseline capable of meeting mission needs. Develop system structure end product (and enabling product) requirements and generate a preliminary design for each system structure end product.	End products in the form of mock-ups, trade study results, specification and interface documents, and prototypes
Implementation	**Phase C** Final Design and Fabrication	To complete the detailed design of the system (and its associated subsystems, including its operations systems), fabricate hardware, and code software. Generate final designs for each system structure end product.	End product detailed designs, end product component fabrication, and software development
	Phase D System Assembly, Integration and Test, Launch	To assemble and integrate the system (hardware, software, and humans), meanwhile developing confidence that it is able to meet the system requirements. Launch and prepare for operations. Perform system end product implementation, assembly, integration and test, and transition to use.	Operations-ready system end product with supporting related enabling products
	Phase E Operations and Sustainment	To conduct the mission and meet the initially identified need and maintain support for that need. Implement the mission operations plan.	Desired system
	Phase F Closeout	To implement the systems decommissioning/disposal plan developed in Phase E and perform analyses of the returned data and any returned samples.	Product closeout

Figure 2.3: Project life cycle phases, Table 2.2-1 in [38].

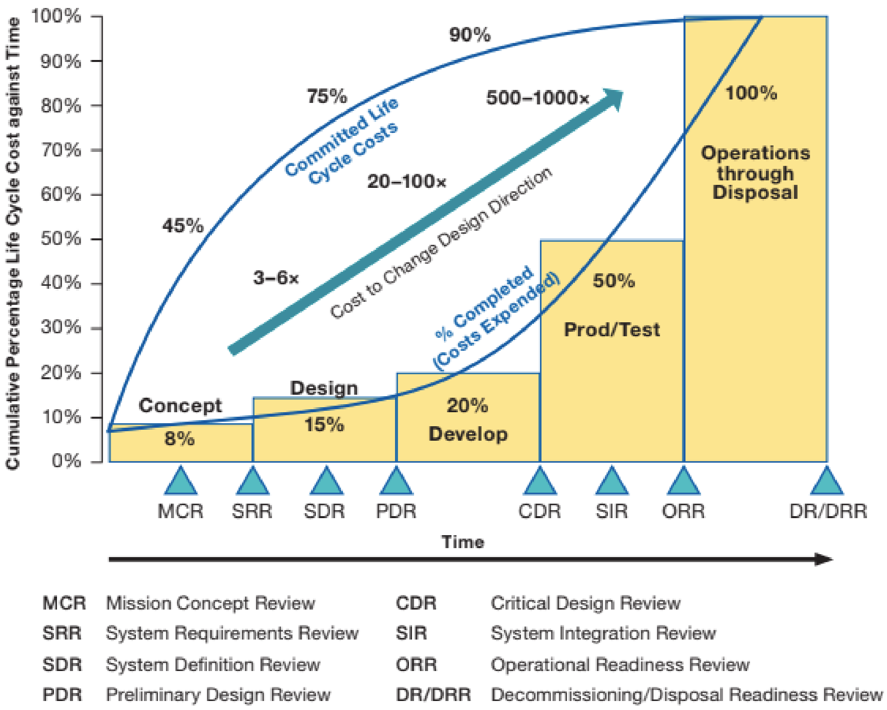


Figure 2.4: Life cycle cost over time and the main reviews to pass, Figure 2.5-1 in [38].

Taking all the above parameters into account a solid timeline cannot be established until funding is secured for both the platform and the science. It is important to keep moving forward with the project nevertheless and after discussion the following is proposed:

- SDR - November 2021: Informally talk through the existing design, ConOps, interfaces with the payload engineers (and EnduroSat), refine the existing baseline so as to pass the PDR. Keep trying to secure funding for the platform, make SSO issue public contract to build scientific instruments so our partners can apply.
- PDR - January 2022 (end phase B): Verify that all partners are on board with the established plans. Requirements should be frozen.
- CDR - October 2022 (end phase C): Every design detail should be frozen. Plan for operations management on the ground is accepted. Ideally, funding is now secured for the science. Start taking care of the logistics behind the testing procedures.
- SIR - February 2022: General checkup on how development is advancing. Frequency bands have been reserved. Ground station is ready.
- ORR - September 2023 (end phase D): System fully tested, everyone is confident satellites are ready to fly.
- Take Off - March 2024: CHESS begins its two year mission.

This is of course an estimation based on little experience with such processes and assuming ideal conditions. Important delays will be accumulated due to funding so the EST. Many teams will change during these years as students come and go. Logistics surrounding AIT, keeping students involved through all stages, and launch of the satellite will be a nightmare. It is important to try anticipate these bottlenecks to minimise their impact where possible. This will require a lot of outside help due to the long time span of the mission and the variables that come with CHESS being a student-led mission.

2.6 Requirements

The requirements of the system ensure coherency towards mission success. They are a set of statements, such as “The Space System shall operate for a nominal mission duration of [2] years in space.”, that define at an abstract level the specifications that need to be fulfilled to ensure mission success. Last semester, as part of the semester project done by Dimitri Hollosi these were broken down as proposed in Figure 2.5. For further detail his report [27] is the best reference. It is necessary, but maybe not sufficient for all requirements to be verified before the mission takes flight. To complete the work done last semester and in preparation of the testing plan, verification methods were added where missing and following the switch to the EnduroSat platform, a selection of those that are still valid was made - marked with “Y” under the “keeper” tab in [26] and [30] (Cedric Chetcutti is making a last review). These requirements have now been transitioned to Valispace that has a great visual representation of their verification status, see Figure 2.6.

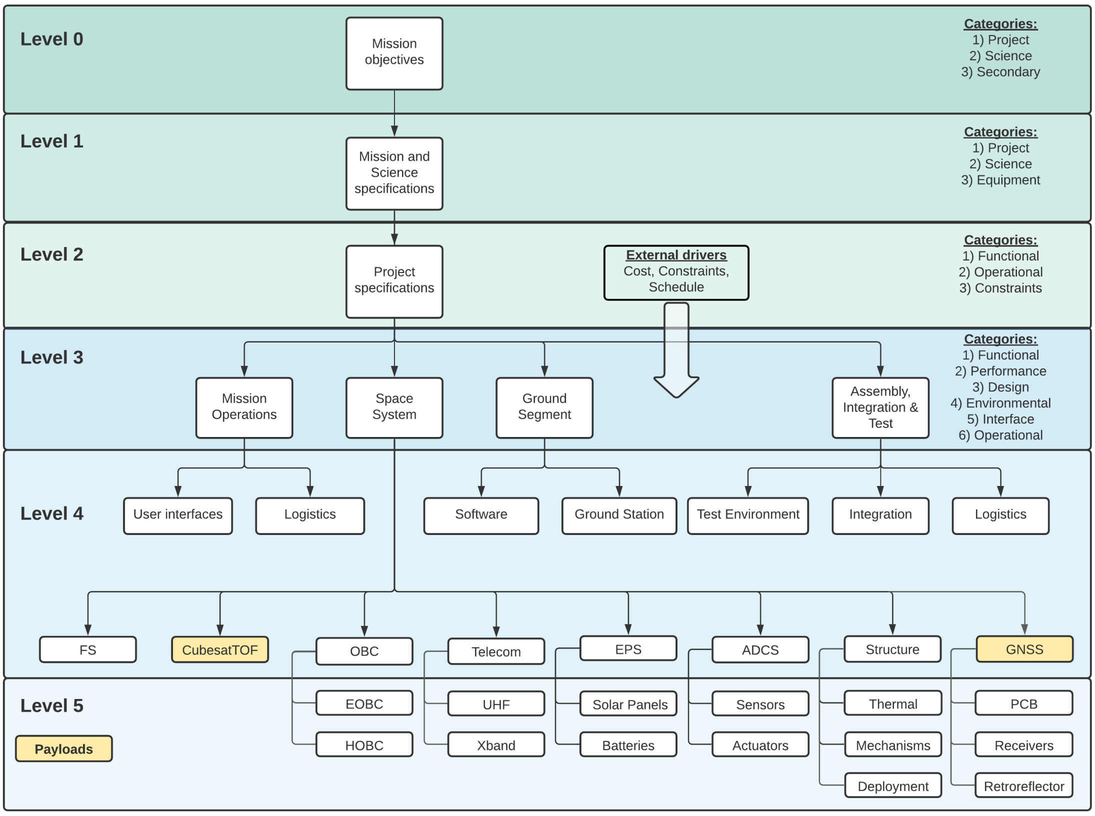


Figure 2.5: Adapted requirements structure breakdown [27].

Figure 2.6: Portion of the requirements tree on Valispace with requirements at different stages of verification.

2.7 Concept of Operations

The concept of operations, ConOps, defines how the system will behave to achieve mission success. In particular, it defines which modes subsystems are in at what time and what action commands trigger. Last year a first version of the ConOps was proposed by Alessandra Capurro and David Sanchez del Rio [1], it was then refined last semester but again, a lot of changes took place and thus, Vincent Pozsgay dedicated his semester project to it to go into much greater detail [41]. He defined a lot of variables related to his ConOps on Valispace but they still need to be properly defined taking into account system constraints (interfaces and budgets). This ConOps variables will also differ between the two satellites. A high level preview of said ConOps is available in Figure 2.7.

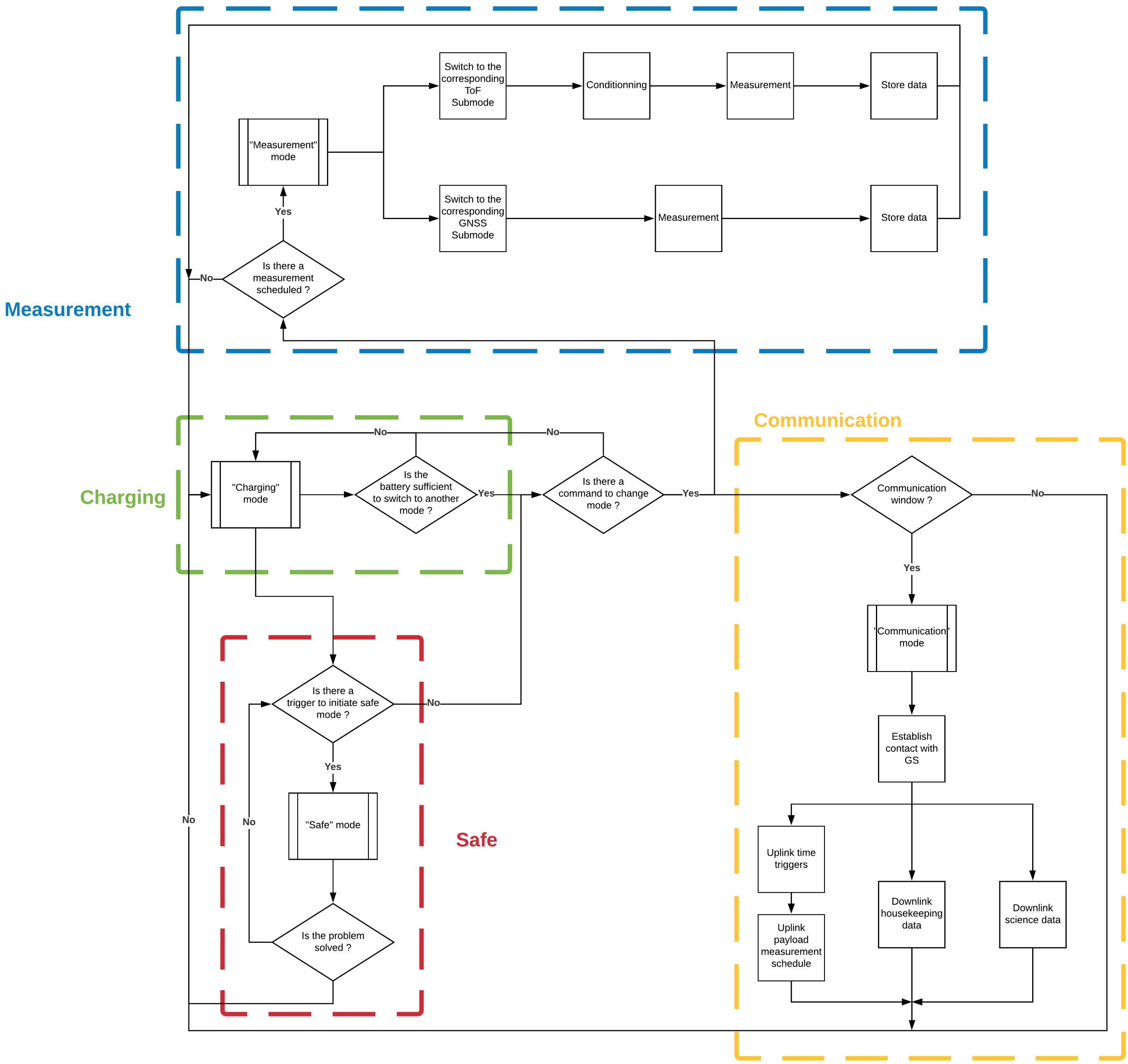


Figure 2.7: Simplified ConOps picturing the 4 operational modes of the satellite [41].

2.8 Space System

The space system refers to the CHESS satellites. Each of these satellites consists of the subsystems and payloads described in this section. The platform, made of the subsystems, is provided by EnduroSat and the payloads by our partner universities and their industrial stakeholders. For an idea of the costs behind all of this, both satellites combined, the platforms are expected to cost up to 500'000 CHF and the scientific payloads up to 1'500'000 CHF [25].

2.8.1 On Board Computer Made by EnduroSat

The on board computer made by EnduroSat (EOBC) is the brain managing mission operations on board the satellite. Its main role is to switch modes as dictated by the ConOps, store information and handle commands/data between uplink/downlink from/to the ground station. A picture taken from the datasheet is in Figure 2.8. This subsystem is handled by the OBC pole. The OBC I module has been bought and received this semester and a few first tests have been made.

Figure 2.8: Picture of the on board computer provided by EnduroSat (EOBC).

Some of the main specifications are that it has a microcontroller running at 216MHz at its core. Unlike with the FPGA we planned to use up until this semester (now HOBC), changes to the pinout would require major hardware changes by EnduroSat which imposes constraints on the pin assignment. It has assigned I/O to support most common communication protocols such as I2C, SPI, UART, RS485. The memory can make use of 2 SD Cards of up to 8GB each. It is equipped with accelerometers, compasses and has an optional slot for a GNSS receiver. Note that in the budgets table in Figure 2.2 the version without the GNSS receiver is accounted for to save up some extra space (EnduroSat said they could reduce the height of the PC104 connector accordingly). This choice is justified by the fact that our GNSS payload is much more capable than the GNSS of the EOBC. EnduroSat currently has the version with their GNSS in their CAD model. If space permits and a thermal analysis doesn't yield any red flags, adding the GNSS configuration to the setup could serve for redundancy. In that case, the antennas of our GNSS payload will still have to be used.

2.8.2 Electrical Power System

The electrical power system (EPS) is the power collection and distribution unit of the satellite. From a system point of view it encompasses the solar panels, the electronics module itself and the battery pack. The CHESS satellites are set to have 4 cell batteries that amount to 42Wh of energy, the EPS II module and solar panels are all provided by EnduroSat. The solar panels are deployable, done once in orbit upon exit from the launch vehicle, and will incorporate a UHF antenna, as explained in Section 2.8.4. A picture taken from the datasheet is in Figure 2.9. These are all handled by the EPS pole. The EPS II module taking several months to build and being significantly more expensive, it was decided this semester to order the EPS I instead to perform some initial tests and get familiar with the device. The main difference between the two is that EPS II supports 12V, 5V and 3.3V output and EPS I doesn't. These 12V are required to power the Xband module and the CubeSatTOF payload.

The EPS subsystem suffered a lot from the change to the EnduroSat platform. The battery was originally planned to store 60Wh and can not store only 42Wh. Although the mission remains feasible and the ConOps is sufficiently high level for it to be adapted through its many variables, we might have to abuse the batteries a little more than originally intended. This point is to be discussed when deciding on the ConOps variables.

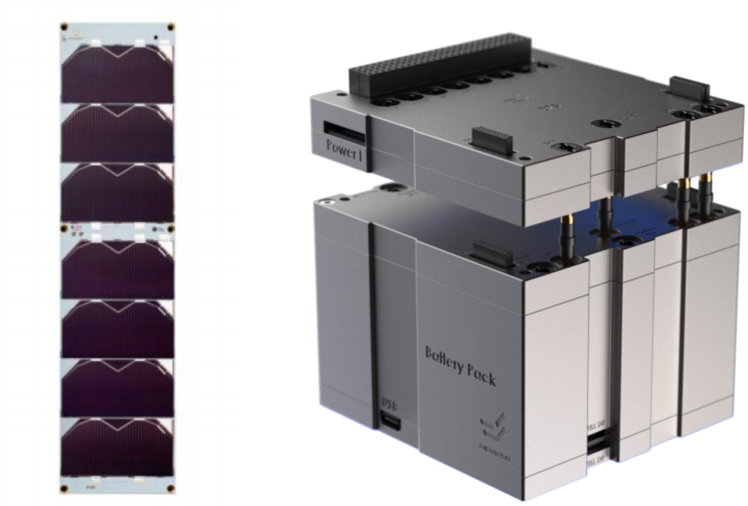


Figure 2.9: Picture of the solar panels and EPS module with its battery pack (EPS).

The solar panels are the first product EnduroSat made, they are very reliable and their business was sort of built on it - paraphrasing David Ryall. There were some ongoing discussions about potentially testing new solar cells Ruag developed but the idea hasn't resurfaced for a while now and seems like a dead end. Additionally, EnduroSat managed to optimize their EPS II module lately and as a result, they estimate a 5mm height decrease. That is to keep in mind when looking at the budgets.

2.8.3 Attitude Determination and Control System

The attitude determination and control system (ADCS) is in charge of orienting the satellite in space so as to point in a desired direction. Although EnduroSat will be the one providing us this module in the future, they actually buy it themselves from CubeSpace and adapt the specifications to their platform. The module consists of sensors (star trackers) and actuators (reaction wheels). Star trackers are cameras that deduce the satellite attitude from pictures of stars in the sky. Reaction wheels are a type of fly wheel that can induce torque on the satellite without the use of thrusters. This subsystem is handled by the ADCS pole. A picture taken from the datasheet is in Figure 2.10.

The pointing requirements are very strict for the CHESS mission as the scientific instruments require to be oriented in specific ways during the mission, see ConOps [8], and the Xband antenna needs to point to the ground station to guarantee the link budget. This ADCS shall provide $\pm 1°$ pointing knowledge and $\pm 5°$ pointing accuracy. A lot of testing of the module took place this semester and the possibility of controlling the satellite with two wheels only was evaluated ([14] still under construction).

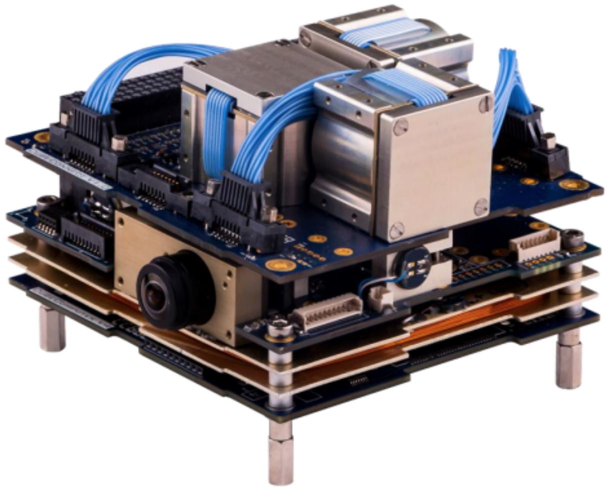


Figure 2.10: Picture of the attitude determination and control system (ADCS).

2.8.4 UHF Transceiver

The UHF transceiver (UHF: ultra high frequency) is in charge of communications with the ground station. This means the transmission of housekeeping data (well being of the subsystems, constant sanity checks during flight) and reception of commands that could indicate the mission plan, request specific information or be used for debug purposes. The latest meeting discussions suggested the antenna will be incorporated within the solar panels and thus deploy simultaneously. This module and the antenna associated with it are provided by EnduroSat. A picture taken from the datasheet is in Figure 2.11. As of next semester this subsystem will be handled by a new Telecom pole. This pole is meant to work in collaboration with Marcel Joss and thus establish better, more frequent contact with HSLU. As of writing of this report, an order has been placed for the UHF transceiver and antenna. The shipment should therefore arrive in time for the next semester.

Initially, the project was set up use radio amateur frequency bands for its communications. However, as a result of our recent fallout with AMSAT (radio amateur community), commercial frequency bands will have to be used. For an overview of the frequency bands, as per the IEEE standard, see Figure 2.12. The procedure to reserve some frequency band for the CHESS mission should be initiated with Ofcom (office of communications) as soon as there is some certainty regarding funding and subsequently the launch date. These procedures used to take years (hence the choice of collaborating the the radio amateurs who had faster procedures) but with recent changes in the legislation for small space missions

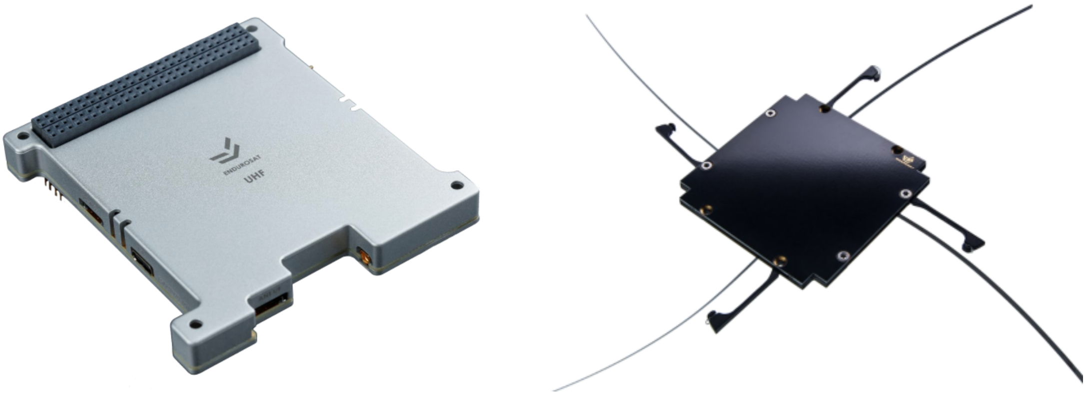


Figure 2.11: Picture of the UHF module and the associated antenna (UHF).

such as CHESS this has been reduced to somewhere between 6 to 24 months (which is equivalent to the time it would have taken with the radio amateurs).

Band designation	Frequency range
HF	0.003 to 0.03 GHz
VHF	0.03 to 0.3 GHz
UHF	0.3 to 1 GHz
L	1 to 2 GHz
S	2 to 4 GHz
C	4 to 8 GHz
X	8 to 12 GHz
K_u	12 to 18 GHz
K	18 to 27 GHz
K_a	27 to 40 GHz
V	40 to 75 GHz
W	75 to 110 GHz
mm or G	110 to 300 GHz[note 1]

Figure 2.12: Radar-frequency bands according to IEEE standard [48].
A list of advantages/disadvantages of using one over the other can be found in [15].

2.8.5 X-Band Transmitter

The X-band transmitter (Xband) is in charge of transferring the scientific data to the ground station. Given our relatively high data volume and short communication windows [27] the higher X-band frequencies are a must. This module will be provided by EnduroSat but has not been ordered yet (too expensive). As of next semester this subsystem will be handled by a new Telecom pole. A picture taken from the datasheet is in Figure 2.13.

Currently our link budgets are not sufficient to safely attest the communication will go

Figure 2.13: Picture of the X-band module and preview of a patch antenna (Xband). (this is the antenna made by EnduroSat, our antenna is expected to have 2x6 arrays)

through once in orbit. Typically a 9dB margin is desired [39] and currently we fall short of that with the Xband [27]. To further extend the communication window Marcel Joss and his students at HSLU have been designing a patch antenna capable of higher gain at lower elevations, see Figure 2.14. The project was initially planned for radio amateur frequencies so the geometry has to be adapted to the commercial frequencies. As a result of the change, the antenna will need about 27% more surface area which is still be small enough to fit the satellite. EnduroSat is expecting a CAD model of this antenna for their final assembly proposition but we do not have it yet.

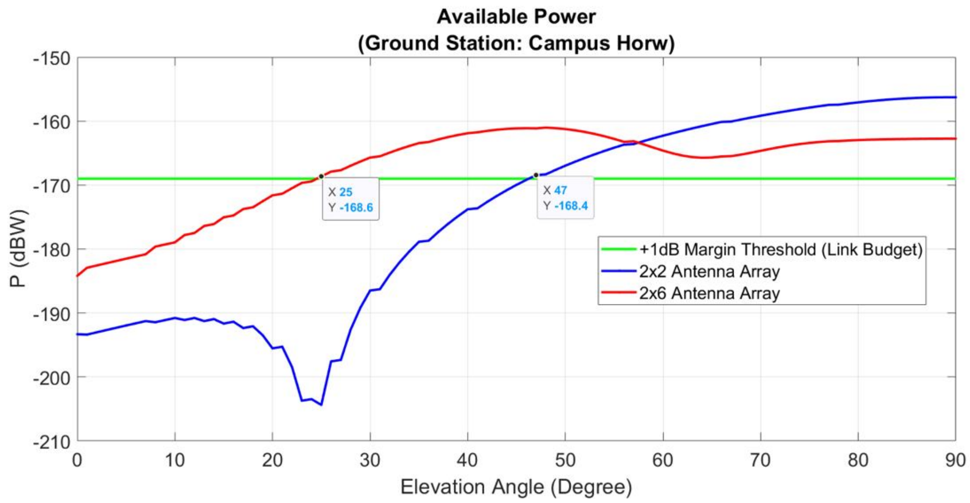


Figure 2.14: Expected X-band patch antenna gain as a function of the elevation.

2.8.6 Multi-GNSS Receiver

The multi-gnss receiver (GNSS: global navigation satellite system) is more than just a classical GNSS receiver like the one EnduroSat provides with its OBC. It has greater accuracy, up to 10 meters (1 sigma) in all directions [30] (usually GNSS systems are not very reliable for altitude measurements) and is capable of scientific measurements [32] from signal alterations occurring in the ionosphere. In post processing we expect to get orbits at the few cm level [36]. This subsystem is made of a PCB, two antennas (ZED-F9P receivers made by u-blox) and a SLR retro-reflector (for satellite laser ranging). In nominal operations the GNSS will provide PVT (position, velocity and time) to the EOBC. As mentioned, it also has five measurement modes [32] accounted for in the ConOps [8]. To verify the accuracy, a laser beam will be directed towards the satellite, reflected back by the mirror and by time of flight the precise position of the satellite will be known (won't be done often). It is provided by ETHZ in collaboration with u-blox. Document with more information about the GNSS and its history are [33], [36]. A preview of the subsystem is in Figure 2.15.

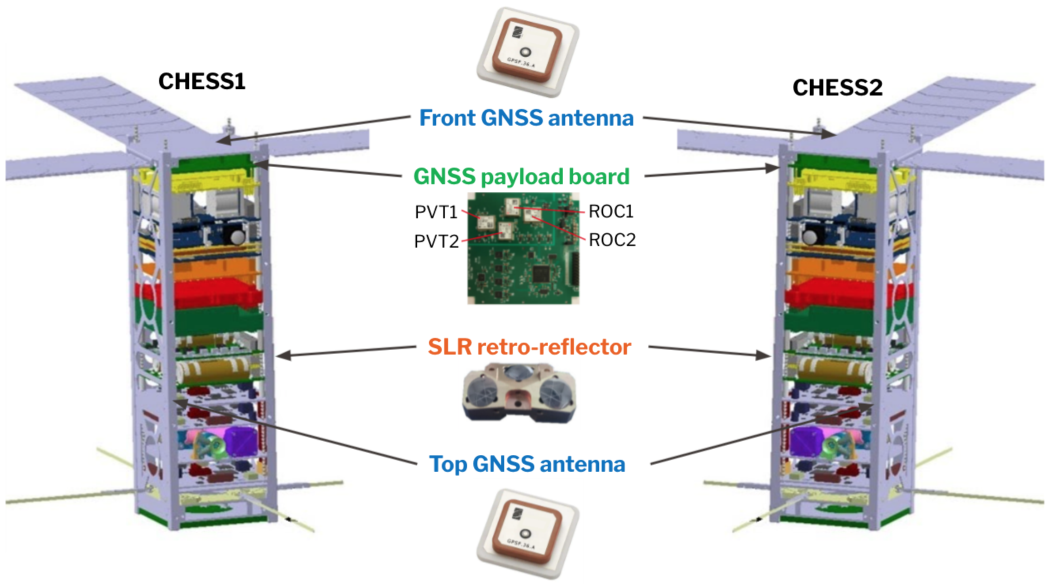


Figure 2.15: Preview of the GNSS payload (GNSS)[11]. (CAD assembly not up to date)

A discussion has been started about the positioning of these components in the satellite. This payload will require some integration procedures to take place in Zurich for calibration of the antennas. It is expected to be ready in Summer 2022 [11].

2.8.7 CubeSatTOF Mass Spectrometer

The time of flight mass spectrometer (TOF) is a masterpiece of technology that fits within a 10x10x10 cm^3. It is responsible for the measurement of neutral and ion species in the atmosphere that drive the entire CHESS mission, making it the most important payload. Modes are switched by the EOBC according to the ConOps [8]. This subsystem is provided by UniBe in collaboration with Spacetek. This payload is currently awaiting the PRODEX funding from SSO to continue development. This may take some time as the funding is subject to a public competition. Upon reception of the money it is expected the payload will take a year to develop. Documents with more information about the TOF are [24], [35]. A preview of the subsystem is in Figure 2.16.

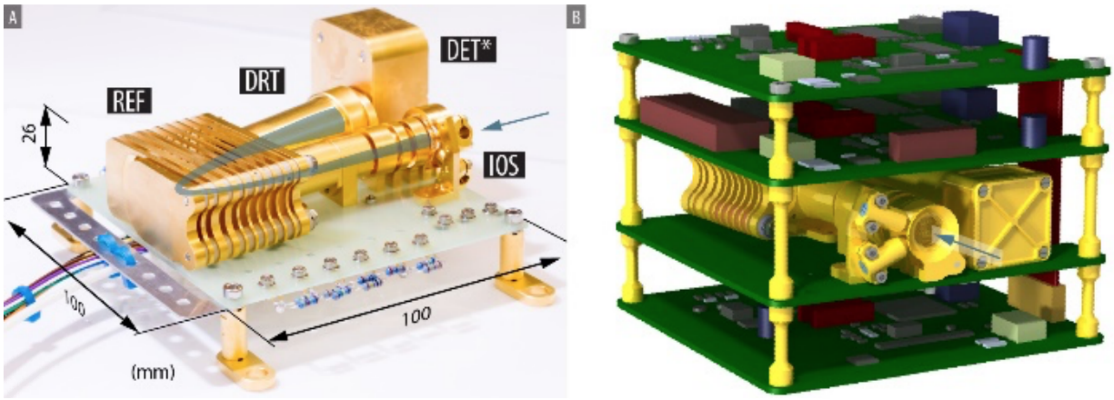


Figure 2.16: Preview of the CubeSatTOF payload (TOF) [24].

To get the best possible measurements, the TOF has to maximise the length of its detector and take advantage of the diagonal space. Unfortunately the PC104 connector, stacked throughout the satellite, stands in the way. To deal with this problem and avoiding modifications throughout the standard platform, it has been suggested, and sort of agreed, to rotate the connector internally. No negative impact on other subsystems is expected resulting from this change. This payload's integration will have to take place in Bern as it requires an especially clean environment to not pollute the instrument.

2.8.8 On Board Computer Made in House

The on board computer made in house (HOBC) has been under development since the early days of CHESS in collaboration with HES-SO under the supervision of François Corthay. It was meant to be the main OBC handling all operations of the satellite, a very capable FPGA reusable on future missions, but as the switch was made to the EnduroSat platform to minimise risk and secure funding the project was dropped. The OBC pole continued to exist, working on different test benches for CHESS and kept developing the HOBC for potential future missions. As the radio amateur payload was dropped it seems we now have space to incorporate it again in the satellite. A modified version of the one originally planned is thus being redesigned to perform some basic tests for in-orbit validation [28]. The HOBC will fly as a payload if EnduroSat confirms space permits to do so. To confirm, they are expecting a CAD model that we do not have yet (all we know is it will be identical to theirs from the outside, for compatibility with the platform). It is estimated that it will be ready before the other payloads, by Summer 2022. A design preview of this subsystem is in Figure 2.17.

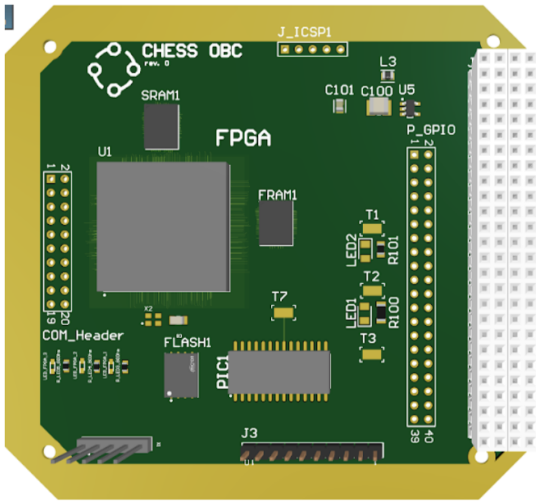


Figure 2.17: Design of the on board computer made in house (HOBC).

2.8.9 Structure

The structure (STRUCT) is what holds the satellite together. Note that a CubeSat unit, 1U is 10x10x11.35 cm^3 [16]. Like the rest of the platform, it will be delivered by EnduroSat. The structure pole handles this subsystem and is expected to ensure successful deployment of the solar panels and along with the UHF antenna. The order has been placed and we expect to receive it before the start of the next semester. The CAD and files we received from EnduroSat are available on the drive [3] and also in [21]. A picture taken from the datasheet is in Figure 2.18.

Figure 2.18: Picture of 3U structure holding the satellite together (STRUCT).

Most of the work done on the custom made structure is rendered useless for the CHESS mission now that it is provided by EnduroSat but educational work surrounding the original one is still taking place. A thermal and vibrational analysis will be performed again by EnduroSat with the new structure as part of the previously mentioned mission analysis. Our mechanical team could do so too and compare the work afterwards.

2.9 Ground Segment

The ground segment of the CHESS mission consists of the ground station in Luzern, see Figure 2.19 for a better idea of what it looks like. The ground station currently operates in VHF, UHF and S-band frequencies and an upgrade is planned for X-band capability. As of writing of this report, the sponsoring team seems to have found a sponsor for the upgrade, estimated to cost up to CHF 150'000. The point of contact regarding the ground station is Marcel Joss. As a backup, the mission can rely on the ground station service provided by EnduroSat, which for a 2 year mission span would have comparable costs. Both options requiring equal funding, cost is not a factor to this trade-off. The two being at comparable latitudes there is no gain from choosing one over the other over this criteria. The advantages of financing the one in Luzern are three fold. Firstly, it will be the first of its kind in Switzerland and thus sets CHESS in a sort of pioneering position. Secondly, as soon as a second EST mission takes flight, we will already have broken-even on the investment and only operational costs will remain. Finally, sharing the ground station with HSLU actually gives more control and insight into mission operations as an educational association, an aspect of the mission the EST cannot further sacrifice at this stage. The disadvantage of using the one in Luzern is that it is not available yet but funding sounds promising and it should be ready when the space system is ready for launch.

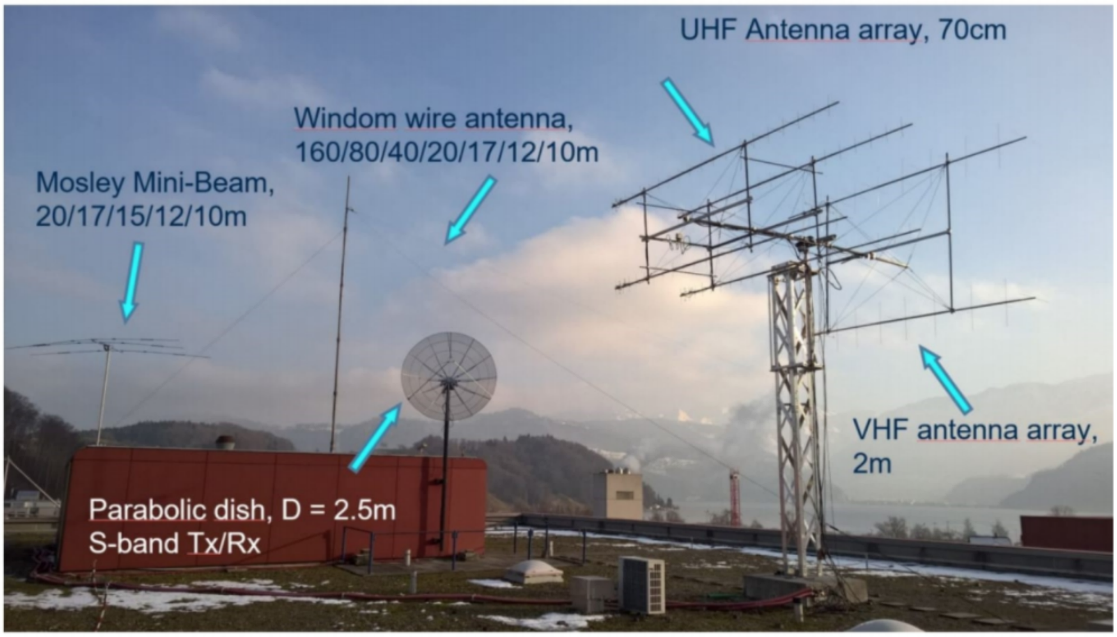


Figure 2.19: Picture of the ground station in Luzern, courtesy of HSLU [27].

A UHF ground station is apparently relatively cheap (1'500 CHF [39]) to build from readily available radio amateur components. David Ryall recommended setting one up here at EPFL (and make it mobile to be able to avoid interference in the city). This could be a great first project for the Telecom pole.

The ground station, according to David Ryall, is easily the most overlooked aspect of a space mission, especially those he has seen designed by students. Although the ground station has been part of the decision making process during this last year, it never made it into the planning stages and further operational questions beyond simple data distribution

[2] have so far been neglected. It should be the responsibility of the Telecom pole, in cooperation with the SE pole, to consider these aspects of the mission and integrate them in the ConOps. Further details and considerations regarding the ground segment are available in [27].

2.10 System Architecture and Interfaces

The architecture of the satellite has changed from the report of Phase A [1]. As a result of the switch to the EnduroSat platform the satellites now have a redundant multi-master architecture (previously centralized at the OBC). By default the EnduroSat platform has the EOBC, EPS and UHF modules capable of taking control of the satellite if something goes wrong. This was previously not possible and too complex with subsystems bought from different providers. Although the system has multi-master capability it is still expected to be used as if it were centralised one during nominal operations. The EOBC will therefore lead all operations and the other modules will be used for debug if something fails. For all subsystems links to datasheets and user manuals have been regrouped in [43].

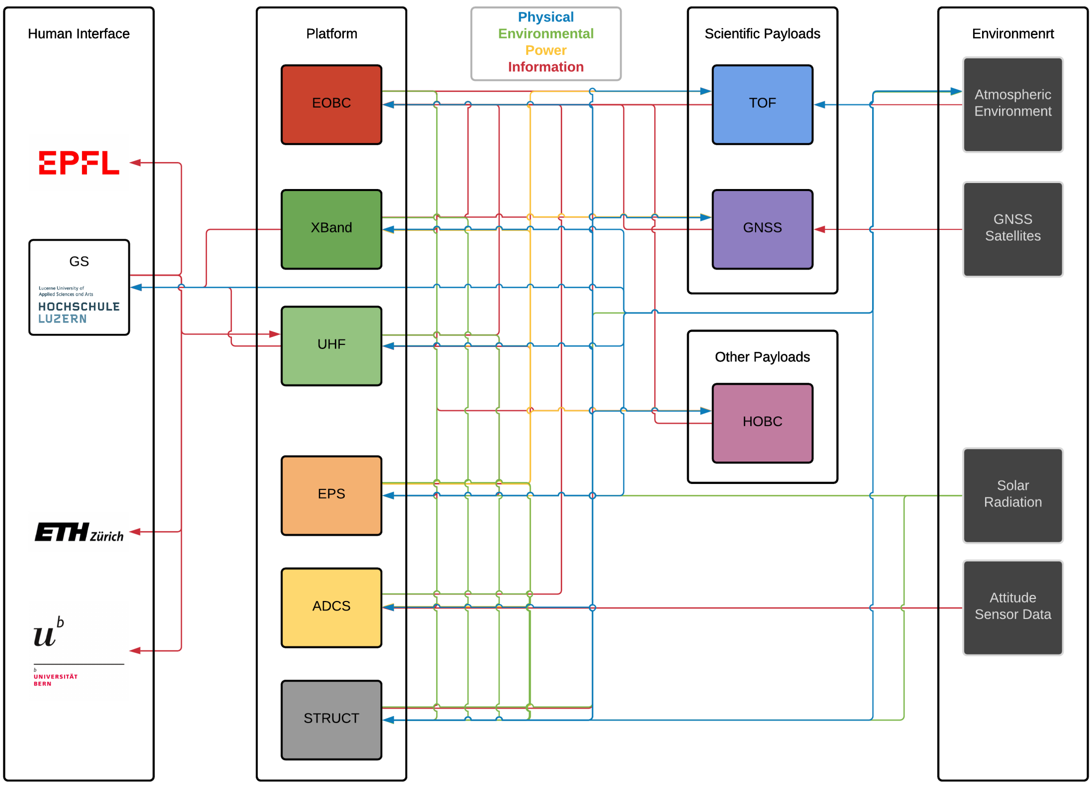


Figure 2.20: Compacted architecture and main interfaces of the satellites [2].

The ECSS standard (European Cooperation for Space Standardisation) on interface management [18] states the customer is responsible for the definition, development and verification of interfaces. “The purpose of the ICD is to define the design of the interface(s) ensuring compatibility among involved interface ends by documenting form, fit, and function”. This is the work that has been taking place this semester, EST being the customer. At this stage of the project, the ICD (interface control documents) are still in the “controlled” stage and not “frozen” so no requirements have been formally issued. Discussions have taken place to reach some form of convergence nevertheless. This is perfectly normal at this stage, a controlled ICD shall be ready for the PDR and frozen by the CDR.

There are different natures of interfaces to consider, see Table E-1 on page 40 in [18]. Of interest to the CHESS project the following have been selected:

- **Project coordination, human interfaces** have been adjusted. That is contact with our new partners seems more frequent than it used to be and on good terms. The internal organization within the EST has been adjusted to better fit CHESS needs and is more centered towards testing. A huge effort has been put forward on the SE side this semester to ensure traceability of information. In students' projects like CHESS loss of knowledge is common and often a critical point of failure. The SE pole should address this throughout the association but it better have it right on its side before criticising others. The SE drive [9] has been reorganised for better access. Documents sent by email to individuals have been shared on the drive and important conversations forwarded to contact.chess@epfl.ch (request login information from management). Valispace as a centralised information center still remains a wish but it is starting to take shape. This report itself strives to provide references to all critical information points, provides a list of contacts and a starting point reading list. Finally, the monthly presentations in front of eSpace helped keep everyone more in the loop, especially during this pandemic with insufficient contact.
- **Space environment interfaces** are now inherently under better control since all EnduroSat modules come shielded to protect against radiation (3mm Al or 2mm Al + 1mm Cu). The idea has been shared with payload engineers.
- **Electrical and data interfaces** will take place through the PC-104 connector. All subsystems have provided us with the pins they require for power and communications.
- **Software** development at HE-ARC was put on hold and redirected towards a weather balloon when it was decided to switch to EnduroSat. Nothing is confirmed yet but it seems like HE-ARC will restart their activities and provide CHESS software for the HOBC. Software for the EOBC will be provided by EnduroSat.
- **Thermal interfaces** have been taken into consideration by the mechanical pole but serve mainly educational purposes as they are incomplete. They did not have the latest CAD and information doing these (no red flags have been raised though). EnduroSat will do a thermal analysis for CHESS to confirm.
- **Structural interfaces** are defined by the CAD model of the satellite based on CubeSat standards.
- **Communication interfaces** are now better defined as well. Within the satellite, data will pass from the antenna to the EOBC and the EOBC redistributes it, as originally planned. On the ground, information downlinked will be redistributed by the ground station and shared with our stakeholders. The major change is CHESS satellites will communicate in commercial frequencies, the exact bands are yet to be defined by Ofcom (office of communications).
- **Operational interfaces** are yet to be defined. The only thing the EST expects is to be in charge of the mission operations although the ground station will be operated by certified professionals in Luzern.

From the above listed interfaces, a design structure matrix has been established in Figure 2.21 for a simplified overview, from there a preliminary PC-104 pinout has been established [20]. This pinout is compatible with the envisioned data flow [2] and ConOps [8] but specificities as to which line is used when are still not defined. A compact view of the resulting architecture with some of the main interfaces is shown in Figure 2.20.

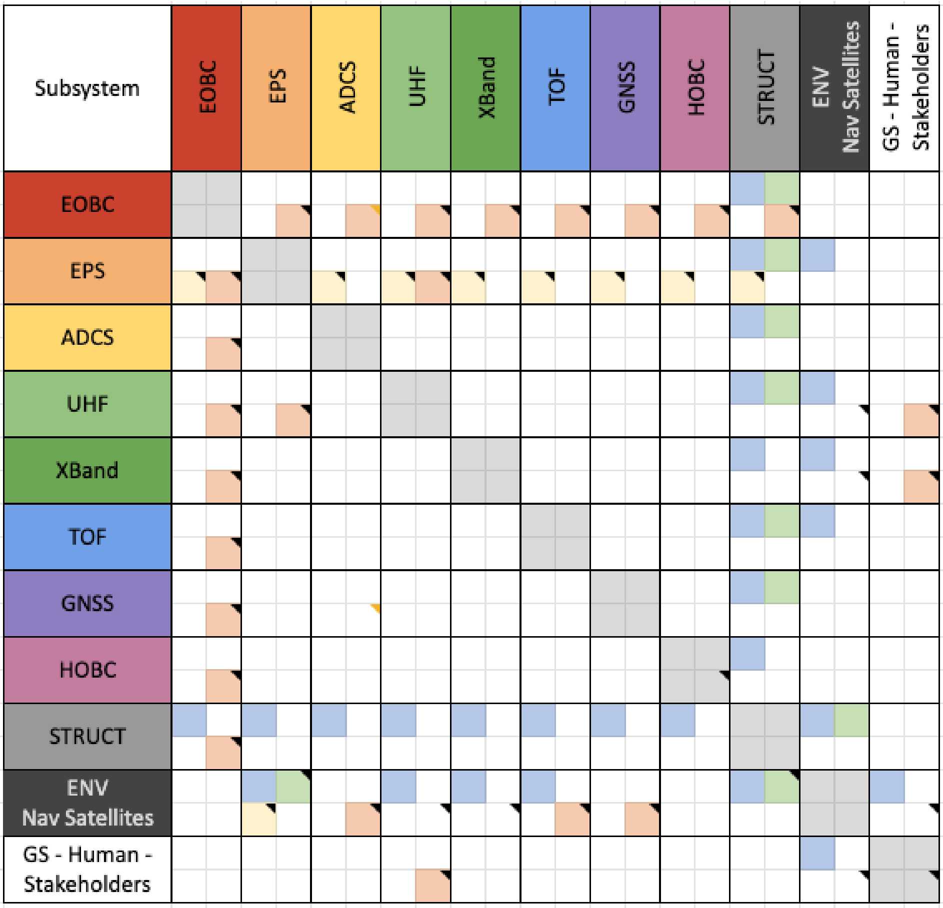


Figure 2.21: CHESS design structure matrix portraying relationships between the components [4]. Further details available at source. Color code for interfaces: Blue → Physical, Green → Thermal/Radiation, Yellow → Power, Orange → Information
Read from row to column, row provides column.

2.11 Risk Management

An important part of systems engineering is risk management. There are different ways to go about it, top to bottom, bottom up, hardware, software and others. Last semester, Alessandra Capurro invested her time into a failure modes effect and criticality analysis (FMECA). This analysis was well layout out in [6] and mentioned in annex of [27] but it wasn't continued this semester as most of the time was spent rethinking the project as a result of the funding issues. However, something important to point out is that they should be done in groups. The reason is people assess risk (severity · likelihood) very differently based on feeling and experience and thus the resulting risk mitigation strategy depends on the people assessing the risk in the first place. This is why the NASA risk sector plot in Figure 2.22 is asymmetric. With the switch to the EnduroSat platform, this analysis has to be entirely reviewed. This risk analysis is meant to guide further design choices that increase the probability of mission success down the road. For more about how to perform a risk analysis, see the courses [37], [47], among others.

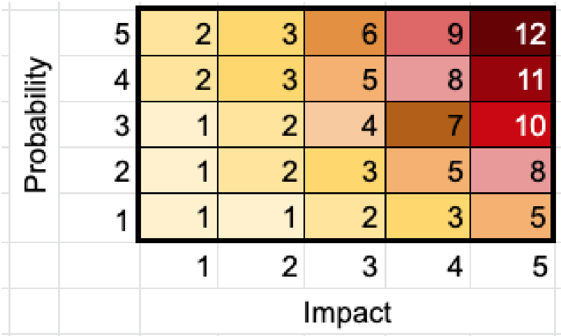


Figure 2.22: NASA risk sector plot [6].

Although no formal risk analysis took place this semester, the Swiss Space Office (SSO) pushed the project into a collaboration with the private sector to reduce said risk (and pushed forward its "international collaboration" agenda). With most subsystems being commercial, with some flight heritage, and the platform assembled by professionals, instead of students, it is safe to say the risks have considerably been reduced.

As a result of this costly decision, the SSO has agreed, in writing [40], to support our mission with its PRODEX funding meant to fund the scientific instruments if the EST can secure funding for the platform. They said they were willing to do so little by little to keep our mission going in the meantime. As a side note, the original letter of intent to the SSO [7] is a good read.

A question that doesn't come up often enough during discussions is "Who is responsible for what?". Unfortunately, we are too early in the project stages to give a definitive answer as no contracts have been signed yet. However, as the project approaches the PDR and then the CDR there shall be no doubt about this for all parties to avoid unnecessary quarrels and project delays. This will have to be carefully crafted by CHESS management with the help of eSpace. The SE pole can assist such discussions with its risk assessment and providing a testing plan all parties agree to.

2.12 Assembly, Integration and Testing

To maintain student involvement as much as possible, yet minimising risk, the idea is for the assembly of the platform will be performed by EnduroSat and then shipped to

Switzerland for integration of the payloads and testing. This assembly, integration and testing process is often referred to as AIT. The details as to how exactly this will take place are to be elaborated further. Paul Wahlen has started working on a plan this semester [13] but so far, except reviewing for a preliminary list of tests to perform on both payloads [34] and [23] no plan has taken shape. The model philosophy described in [27] still applies: one flatsat (engineering model) and two satellites (one proto-qualification model and one flight model) will be built. Last semester, Celia Hermoso selected the tests in [5] for our CubeSats based on ECSS standards. It is recommended to have more than two satellites, not to fly the ones damaged by exhaustive testing but so far funding options to build more of them are not available. To avoid damaging the models expected to fly the testing will be milder, to what extent is still unclear.

The CubeSat industry is very new, some companies try to manipulate their flight heritage numbers to get on top of their competitors. It is therefore advised to extensively test all subsystems (reasonably) to guarantee expected behaviour. Testing is a great way to learn about the subsystems themselves. The re-organisation of the EST for the CHESS mission next semester intends to assign at least one person per pole to the testing of their subsystem. It is advisable to assign a system engineer, to collaborate with them on the matter, organise weekly meetings and plan the procedures together so as to verify the requirements. The OBC and ADCS poles might be able to help out as they already have some experience from work done this semester. Bear in mind that the project still lies at very different stages between the subsystems.

Logistics will be a hard aspect of this project after the PDR. It is important to try to anticipate the next steps, allow for buffer times, secure transportation and facilities for the satellite beforehand. The platform and payloads have different technological readiness levels (TRL), triggers for development and delivery lead times that should be accounted for. Also remember that tests of individual components do not guarantee everything will work once connected together and integrated in the satellite. Furthermore, as mentioned briefly in their respective Sections 2.8.6 and 2.8.7 both payload stakeholders want/need part of the testing to take place in their facilities.

2.13 Verification and Validation

The verification and validation of requirements are sometimes referred to as V&V. In a nutshell this the difference between verification and validation is described in Figure 2.23. The verification usually takes place internally and then the results are submitted for validation to external stakeholders. This work is closely linked to testing. Each requirement should have a verification method associated to it. On Valispace these requirements form a tree as in Figure 2.6, they can be marked as verified or not and until all of them have not passed their tests, the branch nor the tree has been verified and does not turn green, see Figure 2.6. Mamoun Alaoui Slimani worked on getting all the requirements from the excel sheet that was prepared last semester onto Valispace.

2.14 Mission Operations

To the EST the mission operations still need to be defined. Its responsibilities towards the CHESS mission will two fold. First, ensure everything is planned for in terms of logistics (transportation, facilities, workforce,..). Second, coordinate mission operations with stakeholders. Taking into consideration the power and communication constraints of the satellites, what measurement is entered and when is an important aspect to the

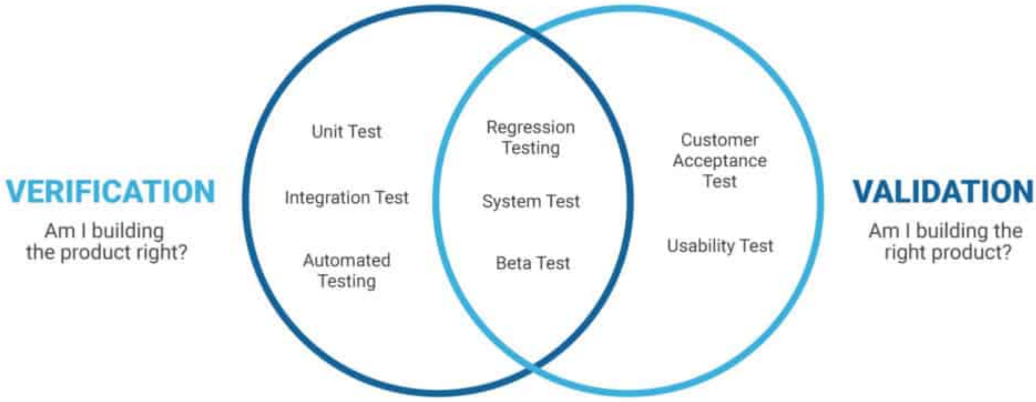


Figure 2.23: Difference between verification and validation of requirements [46].

mission. This also implies debugging potential failures, that will hopefully be part of some of the scenarios prepared for in advance as a result of the risk analysis. This is one more reason why it is very important to test all the subsystems and build up "how to knowledge" within the team. A flatsat will be available to help locate, reproduce and troubleshoot these issues.

The expected life time of the mission is planned for two years. At the moment it is considered that the mission will come to an end when all the main stakeholders (who have a payload on board) agree to it. The mission could also be forced to an end if a critical system fails, if the reservation of our communication bands come to an end. Partners may drop out, in the event of a partial failure of their payload for example, and the mission still continue. At the very latest the satellite will have to be decommissioned within 25 years to avoid accumulating space debris [22] (should happen much earlier for CHESS satellites). The best way of decommissioning our satellites will be to orient the solar panels so as to increase the drag coefficient and wait for the satellite to burn in the atmosphere. The EST will be responsible for the end of life of its satellites.

3 Semester Project Insights

3.1 Work accomplished

The work accomplished this semester was documented in [42] on a weekly basis. The last semester ended on a note that to secure funding from the SSO we might have to shift the project in another direction. First thing this semester, it was announced we would now work with EnduroSat. Work related to interfaces was therefore delayed until the the situation was cleared. Many discussions took place during that time considering the main trade offs resulting from the change and what it implied for the association. Requirements were reviewed and shared with EnduroSat. After a month, with Dimitri Hollosi, we felt we knew enough about the project to fully involve our new members who were still familiarising themselves with the project. Unfortunately, they were all first year students, EPFL life kicked in and they couldn't contribute as much as they were hoping to anymore. As a result from the shift to the EnduroSat platform the architecture of the system changed to a multi-master system, this provides CHESS a redundancy it didn't have. My work was mostly focused on establishing the interfaces between the subsystems. The results of this work are in Section 2.10. Most the time was spent comparing documentation and evaluating communication options for our payloads. This is because a lot of the information in these datasheets is either erroneous or ill-defined which required going back and forth with EnduroSat. It is only towards the end of the semester that we reached a consensus and they provided us with a complete PC104 pinout of their platform to which we could add whatever we desired. In the meantime, time was spent helping out with the ConOps, establishing a data flow diagram, reviewing requirements in preparation of the testing plan, verifying and checking non PC-104 interfaces which ultimately led to establishing a budgets sheet and, unfortunately, to the removal of the radio amateur payload. Time was invested into reorganising the information on the systems engineering drive for better accessibility and making information traceable. All important conversation by email were forwarded to contact.chess@epfl.ch for the next team to pickup. Most meetings were documented for future reference and we made presentations to keep eSpace better involved in our activities. Both were big "to do"s left hanging from last semester. To conclude the semester we then submitted our application to the IAF competition.

As a result of this work, hopefully the next team will have an easier start than we did a year ago. We now have a clearer view of the platform provided by EnduroSat and the data flow between the subsystems. I am happy to say I believe CHESS will not have to suffer through any major changes anymore. The next team will have to work closely with the other poles to establish testing plans that verify requirements (and maybe add a few to the list) and ensure the ConOps is feasible. The interfaces should guarantee all ConOps needs are provided for but no work went into checking the interfaces were not overloaded for lack of time and readily available information.

3.2 Assumptions

The work done in SE operates under the assumption that we will eventually get funding for the mission. In the meantime we accept that work won't necessarily go smoothly, as implied by the timeline proposed in Section 2.5. We also operate under the assumption that anything can go wrong and opt for redundant solutions where possible. Finally, we have to assume EnduroSat knows better than us in most situations. Although their datasheets left to desire, they are a great partner for us, learning as we go as well.

3.3 Critical Review

CHESS is a student-led mission which now seems to have turned semi-professional. For a while this semester it was no longer about the education of the students but it turned into project survival. Decisions got blinded by the funding issues and trade offs got a bit over-simplified. Fortunately, events turned out well throughout the semester and the association is now back with a plan to focus on the educational aspect of the project with its initial partners involved again, to a lesser extent for some of them. The educational work will now take place mostly around testing, the part of a project that is usually annoying to engineering students who rather seek to design and make. That doesn't mean it has to be boring. Management is working on project ideas that could be worked on in parallel. The two projects running in parallel could bridge the gap between the CHESS needs and education, discovery of what it takes to build a satellite.

In terms of systems engineering work the general feeling is that we have done our job this semester, CHESS has been set on a nice track for its future steps. Having taken the courses [37], [47] in addition to being involved in the association since last semester came in useful and was a great preparation to the work accomplished. The supervision of the project gave enough space for students to lead the mission and was there to help with specific issues, always suggesting, never imposing, and asking for external help when necessary. I find I did a good job pointing out issues that came up, or things that felt wrong, along the way and we came up with some form of solution most of the time - "proper paranoia". It was my pleasure to be involved in high stakes decisions and being involved in a variety of problems - not stuck working on interfaces only, although I learned it always comes down to the interfaces in the end. I personally feel that CHESS is in good terms with its partners, especially our new one, EnduroSat. Important decisions were taken together with the affected stakeholders and contacts were sufficiently frequent as well. Some discussions are still ongoing so it is not completely a blank slate for the next team but we made a list of contacts in Annex B to mitigate issues that could arise from that. We also hope we can meet with them to discuss about the project during and hand it over properly, in person.

However, several things could have been improved. Regarding the team, I am sorry we didn't advance more on the tasks assigned as part of an association project. Truth is some of the tasks were probably too hard or did not seem relevant enough but EPFL life hit the team a bit too soon and I barely got in contact with some of them after that. We probably could have done a better job at keeping this team together. The covid situation and our very different schedules did not make it any easier but with the smaller team we had last semester we handled that much better. Only half the people attended our weekly meetings and they weren't of the most productive either. It was a different story with the credited projects. They all advanced pretty well and a lot of uncertainty was eliminated. However, our meetings were unprepared and often just a lot of talk with no outcome. Not that the conversations were useless but they were inefficient. I learned from that and by the end of the semester, every meeting had an agenda with an expected outcome, ideally discussed in advance. Many meetings got shorter as a result. In terms of the work, I tried to preserve everyone's role by not doing the work of another person but I waited too long before I considered reassigning some of it which led to unnecessary delays. We might have known a month earlier that the budgets clearly showed we had no space for the RA payload. I was not as proactive as I would have liked to be, a little push from time to time could have helped. That push came during the writing of this report where I fixed most of the issues with the PC104 connector by communicating better with EnduroSat. At first

I was just asking questions trying to figure out myself why I didn't get it but the when I laid out the problems and asked for help they were far more responsive and gave me a direct answer. I feel like systems engineering, in this project, is far more about human interfaces than it is about anything else.

A final note on Valispace: EnduroSat is willing to use Valispace if we give them access, the extent to which this would be necessary still remains unclear but it could be a way to push it forward. A mistake I believe was made is the SE team tried to push forward, a software that is not so obvious to use to a team that did not really need it, maybe this will change when testing time comes. I suggest organising a meeting with the next team to discuss the utility and willingness of using Valispace and simply dropping it if the idea doesn't pass. A lot of time has already been spent on the subject with no avail so it is time to reconsider the approach. It was intended we build a model of the satellite the EST could reuse for other missions in Valispace as part of the MBSE approach (model based systems engineering) taking over the industry but it never got close to that.

3.4 Recommendations

Following is a list of recommendations we came up with after working on the project this past year:

- Keep track of the work done each week. It imposes some kind of pressure that makes things move forward and is a nice starting point for the weekly meetings. Also useful to have when writing end of semester reports.
- Meet in person whenever possible. In person meetings make it easier to trust, build a team and keep a team together.
- Take time to properly read through the documentation and get a deep understanding of the project, could take weeks. Read through the NASA handbook [38].
- Attend pole leader meetings when possible. It is the fastest way to get familiar with the project.
- Ask a lot of questions, especially those that come out of nowhere. Doubt whatever is unclear and verify it. Keep a trace of your findings. Michael Linder wants to establish a wiki for this.
- Directly contact the person in charge when dealing with an issue, cut through the pole leader hierarchy. The same goes for other conversations. If you end up being just a relay point, get out of it.
- EnduroSat is very responsive to emails and a direct approach is preferable, quickly put the question in situation and get to the point.
- Use Slack or email to contact people working on the GNSS payload, generally fast to answer.
- Use email to contact people working on the CubeSatTOF payload, might take some time to get an answer.
- Know that people working on this mission want to see it fly as much as you do. Although they might know more than you do they know exactly what they got into so just say whatever is on your mind.
- Don't wait to have a "sufficient amount of questions" to justify an email. Better make more frequent contacts and get answers than keep waiting and maybe forget

something.

- Respectfully communicate on a first name basis.
- Beware of the EnduroSat documentation when taking decisions, some of it is still under construction. Check coherency first.
- Keep it simple, stupid principle (KISS). When complexity seems to be getting out of hand, there is probably a simpler way.

Lastly, after the many changes that took place this semester, we should contact our partners to introduce the new team and inform everyone of where the mission stands.

4 Conclusion

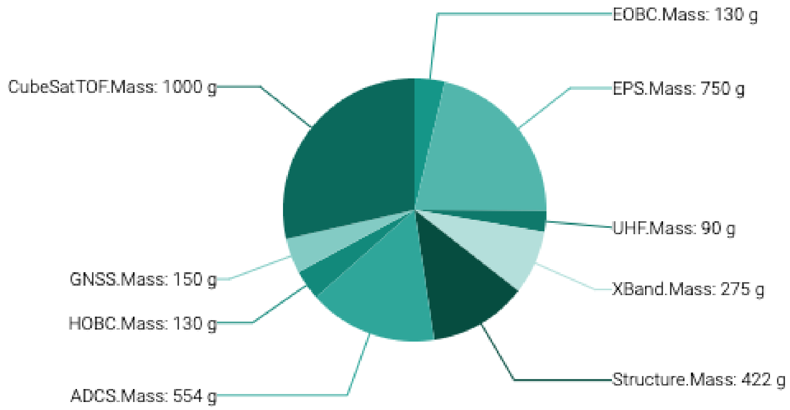
To conclude, a lot of uncertainty been cleared this semester. The devil will now be in the details. The platform and payloads now being out of the hands of the EST, the SE pole now has to plan the merger of the two for mission success. Ignoring the funding issue, testing will now be the most important focus of the project. Before doing that one needs to better merge the ConOps to the data flow to know what there is to test in the first place and complete the associated requirements. Remember that a subsystem passing all individual tests still doesn't guarantee it will work as expected once integrated in the satellite. Some of these tests will require access to special facilities one needs to start planning for in advance. Following the expected deliverables of each mission review should set CHESS up for success. Just keep it going. Good luck.

Acknowledgements

I would like to thank the EST for allowing me to contribute to the CHESS mission. I joined as a newbie and throughout this last year I learned more about the space industry than I could have imagined. Thank you for trusting my judgement and decisions along the way. I would also like to extend the my gratitude to eSpace who make this whole MAKE project possible and Simon Hamel, our supervisor, for helping us out.

Appendices

A Valispace



Component	Mass
Space_System	3501 g
ADCS	554 g
CubeSatTOF	1000 g
EOBC	130 g
EPS	750 g
GNSS	150 g
HOBC	130 g
Structure	422 g
UHF	90 g
XBand	275 g
Total	*3501 g*

Figure A.1: Example of a mass budget analysis generated by Valispace (without margins).

B List of Contacts

A general list of contacts is kept updated in [29]. Following is a list of the students who helped shape this semester's work in SE, leaving the project but still willing to help.

- Dimitri Hollosi — dimitri.hollosi.epfl.ch
  defined the requirements
- Filip Slezak — filip.slezak@epfl.ch
  defined the interfaces
- Vincent Pozsgay — vincent.pozsgay@epfl.ch
  defined the concept of operations
- Cedric Chetcutti — cedric.chetcuti-pouliquen@epfl.ch
  helped out with system engineering in general

Important conversations conducted from personal emails should have been forwarded to contact.chess@epfl.ch, or will be when reopened.

C Getting Started with SE

The following is a list of reads relevant to the SE for the CHESS mission in ± decreasing order of importance.

- Fundamentals of Systems Engineering [47]
- ConOps [8]
- Requirements [26], [30]
- NASA Handbook (relevant sections only) [38]
- Semester Project Report by Dimitri Hollosi [27]
- Semester Project Report by Vincent Pozsgay [41]
- EnduroSat Main Documentation [43]
- Spacecraft Design and Systems Engineering [37]
- Semester Project Report by Alessandra Capurro and David Sanchez del Rio [1]
- ECSS Recommendations [19]

Talking about it within the team is still the best and fastest way to catch up.

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