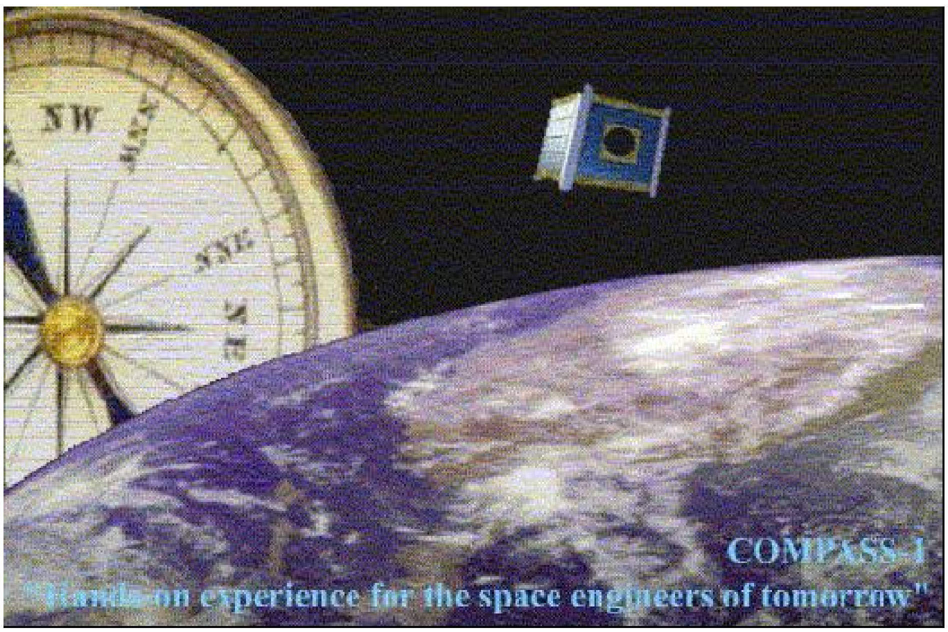
COMPASS-1

Concept Study Report



Preface

This report is part of the COMPASS-1 project initiated at the university of applied sciences in Aachen, Germany (FH Aachen) in spring 2003 with the aim to promote space-engineering activities among the local students. The definition phase of the project is limited to astronautical engineering students of the FH Aachen whereas the development of subsystems is open to students from different departments and study disciplines.

The report describes the results from the Mission Analysis and Design process. Its purpose is to validate the feasibility of the project and to establish the baseline for the subsequent project phases.

This document serves as my study work that is part of the educational training at the FH Aachen and is done by myself.

Artur Scholz

Contents

1. Introduction

With the recent revolutionary development of electronic equipment for information handling and reduction, it is time to think about the changing role of space satellite engineering and about modifying this field, keeping it's strength which consists essentially of the ability to handle systems of high complexity. In sequence of the size reduction of electronic devices, also other components of systems will be subject of an effort to be reduced.

During the last half-century, the work of space satellite engineers was characterized by the development, design, and construction of large devices. Nowadays however, *small* satellites are becoming increasingly important to the space industry. This new space technology is today matured so that spacecrafts and payload dimensions and weights have been reduced. Missions based on small satellites can be conceived and realized at a reasonable cost.

Promote development of small satellites at the Fachhochschule Aachen will provide hands-on experience to university students in space technology. It is an important tool to provide space technology research environment and to train space scientists and engineers of this new small satellites tendency in future. Alike other Universities around the world, the Fachhochschule Aachen has to take this initiative.

The idea to build a satellite at the FH Aachen emerged out of the 3rd year lecture 'Systemtechnik', held by Prof. Dr. Klaus Wittmann. To accomplish such a complex enterprise guidelines were indispensable. By chance the CubeSat concept, developed by Stanford University, offers an ideal approach to achieve our goal of developing a small satellite and having it launched into space. The very low costs, rapid timescale and manageable proportions make the CubeSat program very attractive for gaining experience in the design and development of small satellites at universities. It will provide excellent expertise in space technology through an affordable small satellite project.

A CubeSat is a cubic-shaped spacecraft with side length of 10 cm and a mass of not more than 1 kilogram. The CalPoly University has developed the Poly Pico-satellite Orbital Deployer (P-POD) that can carry up to three CubeSats at a time. In this way the CubeSat developers do not have to be concerned about the interface of the spacecraft to the different launch rockets. The only interface specifications the developers have to meet are those of the deployer. P-PODs are launched as secondary payload, hence enabling low launching costs. This fact is an important matter for universities, as they have to face generally low budgets.

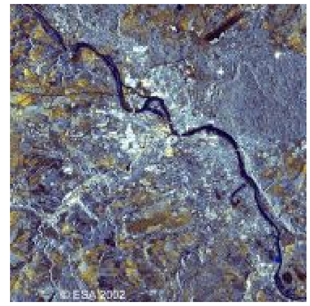
The students usually design and launch in about 1.5 academic years the spacecraft according to mission and payload requirements. The complete satellite life cycle from feasibility analyses to design, implementation, launch, in orbit operations, data collection and interpretation is to be covered by student teams. This will provide an ideal opportunity for training students of different disciplines.

2. Mission Characterization

This chapter describes the choice of the mission and its origins. The needs are expressed and analyzed with regards to the constraints the project is exposed to. The external interfaces are addressed and initial overall mission design solutions are investigated. The unconstrained mission options are numerous, considering all possible parameters for the system elements. The goal of this chapter is to prune this number of options to a reasonable level without discarding options with considerable advantages.

2.1 Background

When in the 60s the first satellites for earth observation were launched they had a radical impact on societies attitude towards environment. Our minds shifted to global thinking, understanding that even so we cannot stop most natural disasters we can prevent the fatal consequences by early recognition. Satellites images provide invaluable information on the earth's condition.

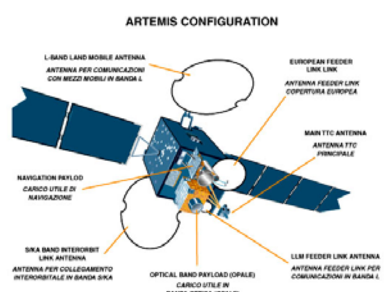


We can basically distinguish different types of disaster e.g. floods, fires, cyclones, volcanoes, oil slicks etc. Some of them are caused by mankind itself whereas others generate from the geophysical activities of our planet. In summer 2002 the eastern parts of Europe suffered enormous from flooding, caused by heavy rain. In Germany several people died and hundred thousands had to be evacuated. Especially in Dresden also many treasures were destroyed or damaged. Those disasters cannot be eliminated but as mentioned before, with a reliable prediction, evacuations and countermeasures can save lives and properties.

To do so, many countries have implemented a process called disaster management in their range of activities. ESA and other organizations work on the creation of models and tools for the early recognition and prediction of such events using images captured by satellite.

Here COMPASS-1 wants to support this process. The spacecraft takes images of the earth and publishes them free to the scientific community (as well as the interested public). People will be able to exam those information for disaster managing purposes.

The other important aspect of the COMPASS-1 mission is to perform a technology demonstration for Ka-band transmission.



The increasing data rates especially for multimedia applications and mobile communication demand for higher frequencies. The biggest story in the satellite industry today is the planned use of the Ka-band frequency range. For ground equipment manufacturers, this promises opportunities and challenges every bit as important as the move into Ku-band a decade ago.

New markets are emerging, driven by applications that presume the availability of increased bandwidth. Low-orbiting satellite systems in the 30-GHz band are ideally suited for these applications, and in fact are the only foreseeable way to provide the needed capacity.

Ka-band frequencies offer many advantages. The primary advantages of Ka-band operation versus Ku- and C-band include increased available bandwidth, reduced interference with terrestrial systems, smaller RF components (especially antennas), and the ability to provide multiple, narrow, high-gain spot beams for extensive frequency reuse.

COMPASS-1 wants to serve as a technology demonstration for a LEO to GEO satellite link using Ka-band frequency. The data from the optical sensor will be transmitted to a relay satellite in GEO orbit (e.g. Artemis). This satellite then downlinks the data for validation. In this way the interfering influence of the atmosphere in Ka-band is bypassed.

2.2 Mission Statement

'Because of the importance of future-oriented training and motivation of prospective space engineers, we as the students of the university of applied sciences Aachen will develop a spacecraft platform, capable to host diverse scientific and non-scientific payloads. To demonstrate it's usefulness we will use an optical sensor for earth observation and a Ka-band antenna for technology demonstration as payloads.'

2.3 Objectives

The primary objectives of the project are:

- to develop a CubeSat (pico satellite) platform suitable for various scientific and non-scientific missions.
- to perform an earth observation mission, using an optical sensor as payload.
- to use a Ka-band antenna for technology demonstration.
- to let the project be completely organized by students, in cooperation with universities and the industry.

The secondary objectives are:

- to make it possible for students to participate at a real satellite project and therefore provide an ideal opportunity for training them in different disciplines.
- to use new technologies and methods, in particular micro & nano technology and to keep the costs at a low level.

2.4 Design Principles

There are two aspects of this project with equivalent value. First aspect is that the students participating in the project will gain a lot of experience useful for their further career. The second is to accomplish a successful mission. In order to do so simple solutions are sought after, consequently to reduce risk of errors.

The project comprises next to the system engineering also the disciplines of project management and product assurance. To cover all disciplines and to conduct the tasks in an adequate manner we will proceed according to the standards published by the 'European Cooperation for Space Standardization' (ECSS). The ECSS documents cover the disciplines space engineering, product assurance and space project management and are available at www.ecss.nl for download. The ECSS documents substitute the older PSS documents formerly published by ESA. The corresponding documents used by NASA are the MIL Standards.

To allow the handling of such a complex project the overall system is broken down into subsystems that can be managed by individuals. The interfaces between the subsystems have to be defined carefully in order to guarantee a reliable and effective system. To each subsystem in the breakdown structure one or more work packages are allocated that precisely identifies the scope of work linked to it.

2.5 Launch and Orbit

The launch of the CubeSats is coordinated by Stanford University in collaboration with the company One Stop Satellite Solution (OSSS). Currently available launch rockets are Dnepr and Eurockot. The first launch of CubeSats into space was coordinated by University of Toronto and took place at June 30, 2003.

Two P-PODs were launched with a Eurockot rocket, of which both successfully deployed their CubeSats. As the CubeSats are secondary payloads the announced launch dates may be subject to change if the primary payload has delays. Hence precise launch dates and orbit parameters cannot be predicted. However past launches narrow the orbits to be likely circular and sun-synchronous with an altitude of 500-700. Throughout the entire document calculations and estimations are based on the following figures:

Orbit:	sun-synchronous
Altitude:	600km
Inclination:	98 degrees

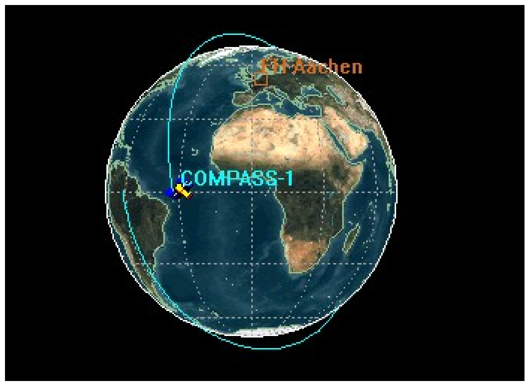


Figure 2.1: A typical orbit for COMPASS-1

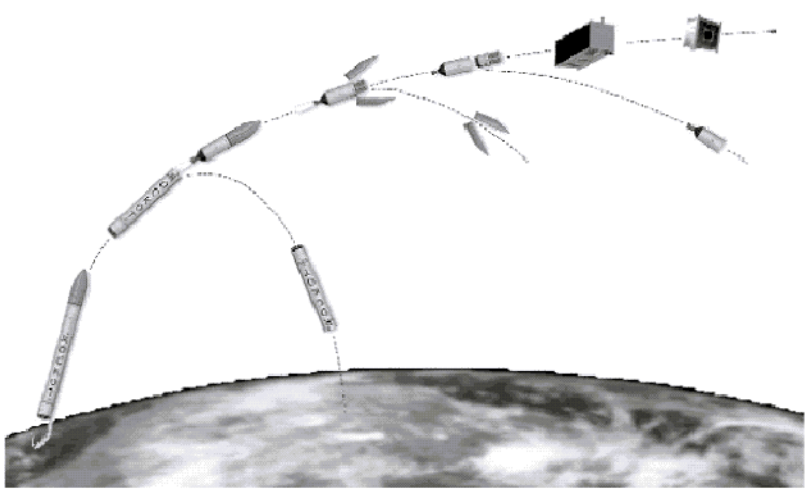


Figure 2.2: Launch sequence

1. The launch rocket lifts of to reach its designated orbit.
2. The P-POD is released as secondary payload containing the CubeSats.
3. The CubeSats are deployed via a spring mechanism.
4. Time delay for about half an hour.
5. The CubeSat goes to de-tumbling mode and acquires a stable attitude.
6. The CubeSat is operational.

2.6 Constraints

For the development of COMPASS-1 Satellite the CUBESAT conventions apply. For further and detailed information please refer to the CUBESAT documentation. It is envisaged to have finished the phase C/D in September 2004. The spacecraft shall be operational for at least one year after launch. The costs for the spacecraft are shall not exceed 50.000 Euro by much. COMPASS-1 is a project aimed at achieving overall control of project risks. Project risk/total cost compromises, which minimize risk, are sought after. Management services are lightened slightly.

Functional Requirements	
Performance	Satellite takes pictures of the earth and sends it down to earth. The image area has to be large enough to enable identifying of costal lines and regions. The images have to be in color.
Coverage	The precise coverage area is of minor interest but it is strongly encouraged to cover a big proportion of the civilized world in order to have a broad group of interested users.
Responsiveness	The taken pictures shall be transmitted towards ground in the fastest way. A picture shall be downloadable in each access windows .
Operational Requirements	
Duration	The satellite and its payload shall be operational at least one year from the time of launch.
Availability	The satellite shall be in reach at least once every 72 hours by the home ground station to get information on housekeeping data and to be able to control its operation.
Survivability	To secure its operational time of at least one year the spacecraft and its components have to withstand the environmental conditions.
Data distribution	The satellite has a small antenna with low power consumption. It is therefore required to collect the transmitted data at ground, prepare it and distribute it via Internet to the end user. The payload data shall be free accessible from any ground station using the designated frequency.
Data content, form and format	The images taken by the satellite shall be onboard compressed into a common image format. It will be split up into packages and send down to ground station.
Constraints	
Cost	The cost for the launch is approximately 30.000 Euro. The satellite components total cost shall not exceeding 50.000 Euro.
Schedule	The definition phase shall be finished January 2004. The launch for the satellite is expected to be in fall 2004.
Regulations	For management, product assurance and system engineering proceedings we will act according to ECSS standards. For radio frequency use international regulations apply. For the development and testing of the CubeSat, Stanford and CalPoly University have published regulations.
Environment	The satellite will be exposed to space conditions in LEO Orbit.
Interfaces	The operator interface depends on the chosen communication architecture. The user interface will be through Internet. User shall have access to the transmitted images freely by visiting the web page of the COMPASS-1 project or by using own ground station equipment.
Development Constraints	The spacecraft development has to be done according to the CubeSat specifications and is restricted in mass, size and power consumption.

Table 2.1: Top Level Requirements

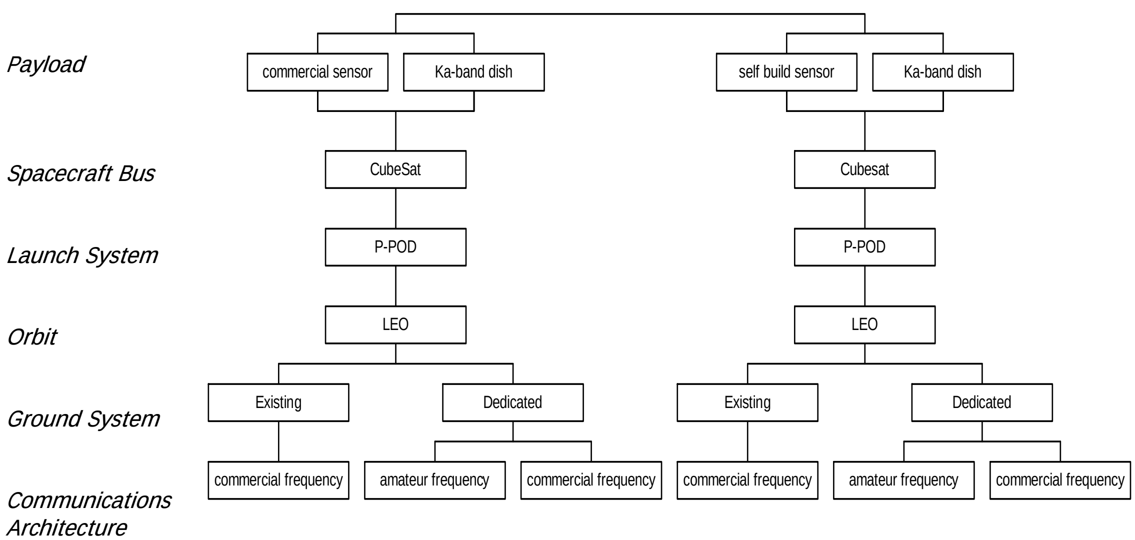
2.7 Mission Concept

The mission concept is the fundamental idea how the mission will work. That is, how the satellite acquires the data, how the data is prepared, transmitted and subsequently received by the ground system in order to pass it on to the end-user. The offered operation modes will be as follows.

1. On request from anyone the satellite returns its housekeeping data that contains vital information of the spacecraft subsystems. Furthermore anyone can request for the image in the payload memory waiting for download.
2. Only the operator can always send a command to the satellite with information about when to take a picture. If there is already a picture in the payload memory it will be overwritten.
3. The operator can also always send special commands concerning the control of the satellite.
4. To transmit a picture via Ka-band antenna the operator on ground sends a special request. This request contains information on the time and the duration of the transmission.

2.8 Mission Architectures

The mission architecture consists of the mission concept plus the specific set of options for the mission elements take make up a typical space mission. The particular elements are the payload, spacecraft bus, launch system, orbit, ground system and communications architecture. Some of the elements are already fixed because of the nature of the COMPASS-1 project. For the elements with various options the next chapters will deal with a solution about how to choose the most appropriate design of the COMPASS-1 mission architecture that fulfills the mission objectives best.



3. Mission Evaluation

The preceding chapter defined alternative mission architectures for the COMPASS-1 mission. This chapter now evaluates the several options and attaches more information to them to facilitate a comparison of the solutions and to finally lead to the selection of a baseline.

3.1 Mission Analysis

The best approach shall be selected that fulfills the mission objectives and requirements. To do the comparison for each mission element option a range of selection criteria are defined. The criteria are the driving requirements for each element. Each criterion is valued with numbers from 1 (low importance) to 5 (high importance) indicated in brackets. The value reflects the impact the criterion has on the mission goal. Those of minor impact are valued low whereas crucial factors are valued top.

Element / Option	**Trade-off**						**Selection**
Payload							
	Low cost (4)	Quick development (5)	Low mass (3)	Low power consumption (2)	Good performance (1)	Sum	
Commercial sensor	1	1	0	0	1	10	X
Self-build sensor	0	0	1	1	1	6	
Ground System							
	Low development costs (4)	Quick development (5)	Low operating costs (3)	Easy access (1)	Modest system complexity (2)	Sum	
Dedicated	1	0	1	1	1	10	X
Existing	0	1	0	0	0	5	
Communications Architecture							
	Low cost (5)	Broad coverage (2)	Small antenna size (4)	Reliable connection (3)	Security (1)	Sum	
Amateur freq.	1	1	1	0	0	11	X
Commercial freq.	0	0	0	1	1	4	

3.2 Selection and Justification

Selection		**Justification**
Payload	Commercial sensor	A commercial sensor is chosen because the tight time schedule and low personal resource do not allow us to spend much time on the development of an own sensor. On the other hand it also demonstrates the feasibility for payloads from a third party or customer. If we will use an commercial off the shelf sensor or contact a supplier to develop one will be subject of discussion for the definition phase.
	Ka-band antenna	The Ka-band antenna will be either ordered or supplied by a collaboration partner.
Spacecraft Bus	CubeSat	The bus concept was not a subject for trade as the project goes along with the CubeSat idea and therefore is inseparable connected to it.
Launch System	P-POD	The launch system is also covered by the CubeSat concept, by using a mother-satellite (the P-POD) to deploy the CubeSats when the orbit is reached. In this way we do not have to worry about a launch interface. The spacecraft though has to meet the requirements set out by the P-POD supplier.
Orbit	LEO	The orbit is interdependent with launch opportunity. The offered orbits up to now are all in LEO and the announcement of future flights show similar orbit parameters for altitude and inclination with past launches.
Ground System	Dedicated	There are several reasons for the selection of a dedicated ground system (which means a ground station from a private supplier, e.g. university), despite the fact that the development time will be longer. Mainly the high operation costs have to be mentioned. Also, we will not be so free in designing the communication link properties if we had to use an existing ground station.
Communications Architecture	Amateur frequency	For the communication architecture we will use an amateur frequency band (L-band). As this is a low cost university mission we cannot afford to occupy a commercial frequency that we have to pay for. An amateur frequency will better serve our cost budget as it is generally free of charge. This outweighs the disadvantages by far for the mission objectives.

4. Requirements Definition

To design the COMPASS-1 system the focus goes from the definition of top-level requirements down to the lower level assembly requirements. In this chapter the top-level requirements are acknowledged and analyzed (using functional analysis) that evolve from the mission objectives and overall constraints. Solutions to meet these top-level requirements are identified. In the next step the requirements for the spacecraft and ground segment subsystems are elaborated. Those requirements emerge from the definition of the top-level analysis process that passes on requirements to lower levels in order to accomplish its functions. Now also budgets become important that divide the margins for mass, power, volume and reliability and assigns them to the several interdependent subsystems.

4.1 Functional Analysis

Elaborating the mission objectives into functions a functional tree can be created, which is shown below. Each main function comprises sub functions that symbolize the starting for requirements definition.

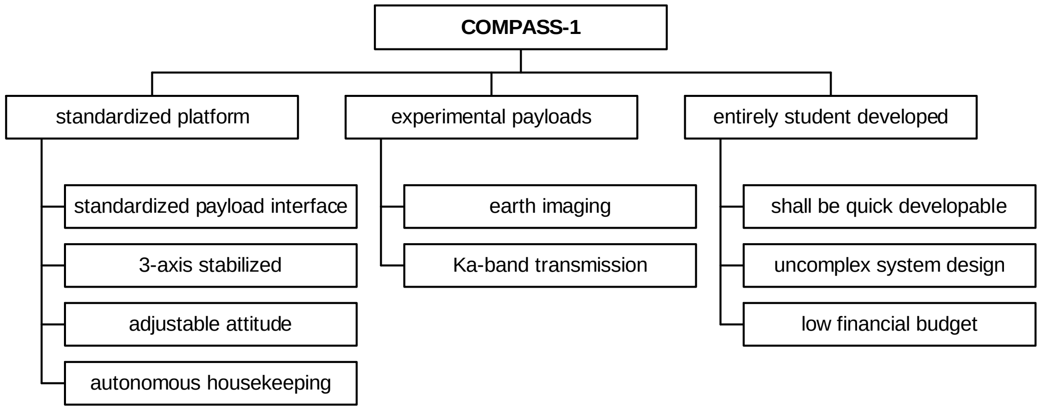


Figure 4.1: Functional tree

Translating the sub functions now into requirements the functional tree transforms into a work breakdown structure, giving detailed insight in the scope of work to carry out as well as the physical architecture of the system.

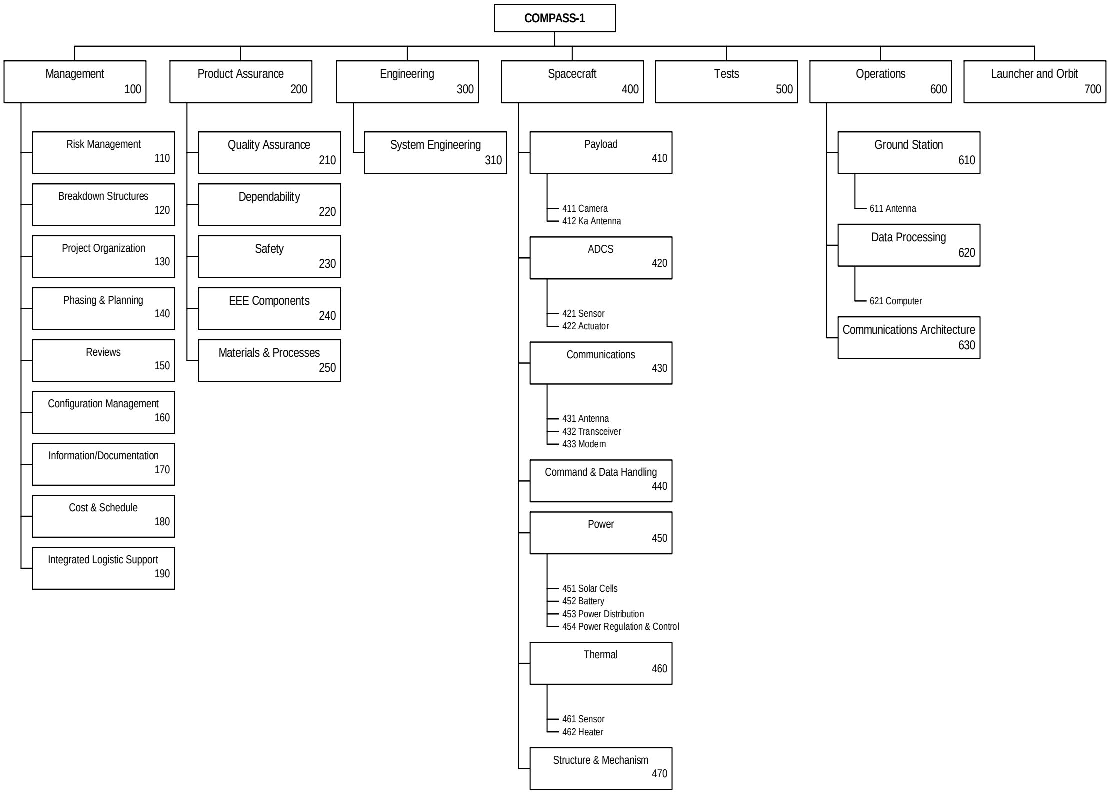


Figure 4.2: Work breakdown structure

4.2 System Design

The following sections reflect the preliminary estimations on the layout and configuration of the spacecraft and the ground segment. During the definition phase the engineering team will work on the detailed definition of the design to component level.

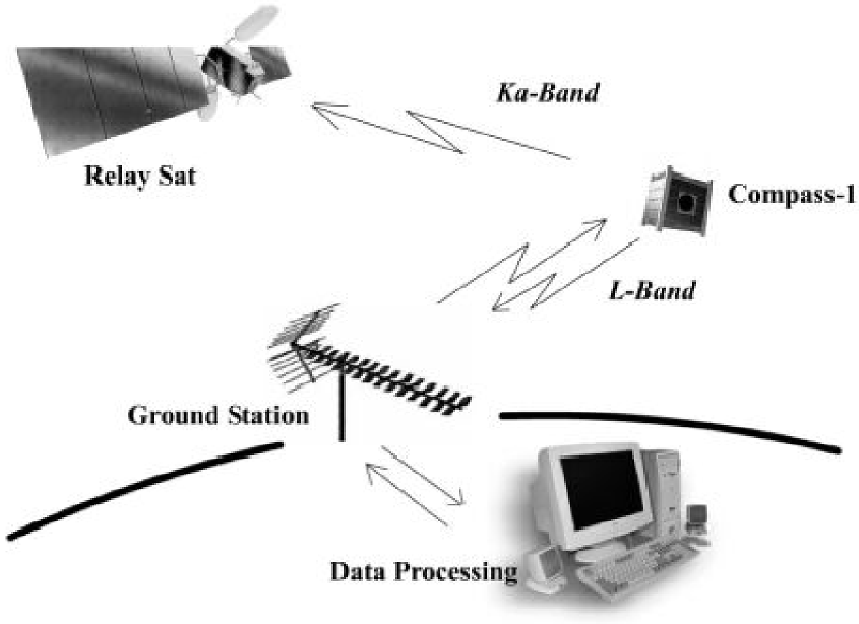


Figure 4.3: Physical Architecture

4.2.1 Spacecraft

The spacecraft layout is shown below. In the front view the optical sensor can be identified, which sits in the center of the top surface. The four omni-emitting antennas provide communication with ground. On the back is the Ka-band dish that is embedded in the cube. On all sides solar cells will be mounted except on the back.

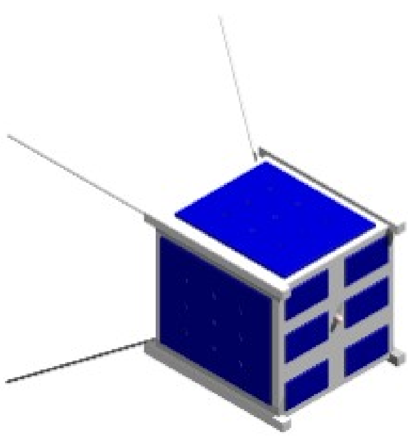


Figure 4.4: S/C Front

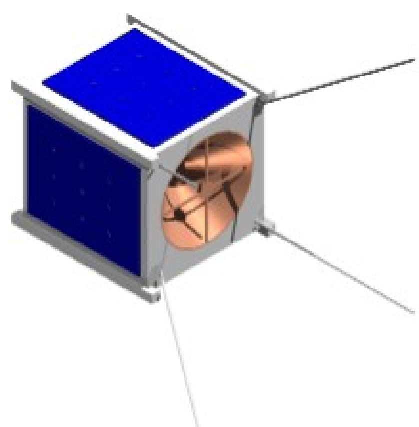


Figure 4.5: S/C Backside

4.2.2 Ground Segment

The design of the ground segment depends on the communications architecture that will be elaborated in the definition phase. The principle layout is given below.

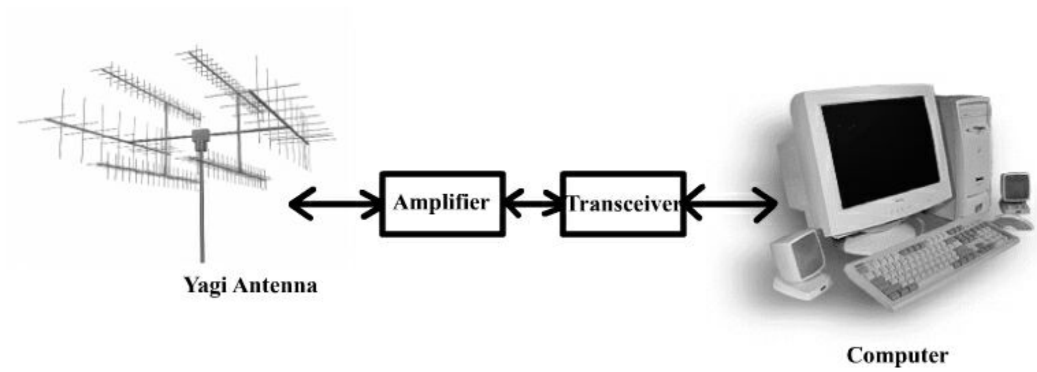


Figure 4.6: Ground segment design

4.3 Spacecraft Budgets

Spacecraft Subsystem	Budgeted		Actual	
	Percent of total	Mass (g)	Percent of total	Mass (g)
Payload	25%	250		
ADCS	15%	150		
Communications	13%	130		
C&DH	10%	100		
Power	15%	150		
Thermal	2%	20		
Structure & Mechanism	15%	150		
Total allocated	95%	950		
Contingency	5%	50		
Total mass	100%	1.000		

Table 4.1: Mass Budget

Spacecraft Subsystem	Budgeted Average		Estimate			
	Percent of total	Power (W)	Standby (W)	Peak (W)	Peak time (%)	Average (W)
Payload	10%	0,10				
ADCS	30%	0,30				
Communications	10%	0,10				
C&DH	30%	0,30				
Power	10%	0,10				
Thermal	8%	0,08				
Structure & Mechanism	0%	-				
Total allocated	98%	0,98				
Contingency	2%	0,02				
Total power	100%	1,00				

Table 4.2: Power Budget

Spacecraft Subsystem	Budgeted Factor	Actual Factor
Payload	0,89	
ADCS	0,90	
Communications	0,93	
C&DH	0,93	
Power	0,93	
Thermal	0,99	
Structure & Mechanism	0,99	
Total without Payload	0,71	
Total with Payload	0,63	

Table 4.3: Reliability Budget

Spacecraft Subsystem	Budgeted		Actual	
	Percent of total	Volume (cm^3)	Percent of total	Volume (cm^3)
Payload	25%	250		
ADCS	15%	150		
Communications	15%	150		
C&DH	10%	100		
Power	16%	160		
Thermal	4%	40		
Structure & Mechanism	10%	100		
Total allocated	95%	950		
Contingency	5%	50		
Total volume	100%	1.000		

Table 4.4: Volume Budget

4.4 Orbit Analysis

The orbit analysis covers the geometry of space mission and lets predict the vital satellites parameters like eclipse times and coverage. The sections dealing with the earths magnetic field and the radiation the spacecraft is exposed to will be subject to detailed studies for the subsystems e.g. ADCS.

The following figures show the ground track of the COMPASS-1 spacecraft for 24 hours and for one month, both starting 1. October 2004.

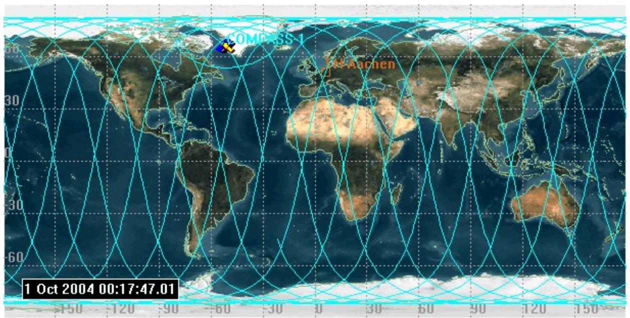


Figure 4.7: 24h coverage

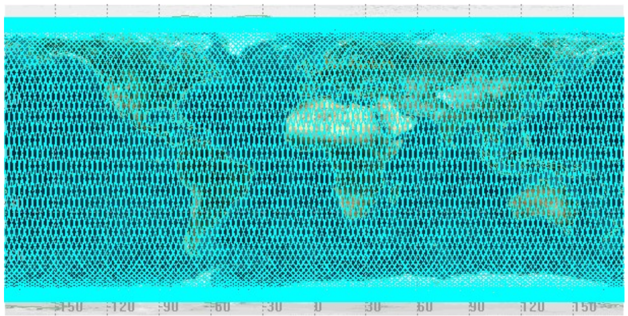


Figure 4.8: Monthly coverage

Sunlight Times	Penumbra Times	Umbra Times
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Mean Duration 3784.707 sec Total Duration 56770.608 sec	Mean Duration 9.909 sec Total Duration 297.259 sec	Mean Duration 1833.258 sec Total Duration 29332.133 sec

Table 4.5: Sunlight and eclipse duration per day

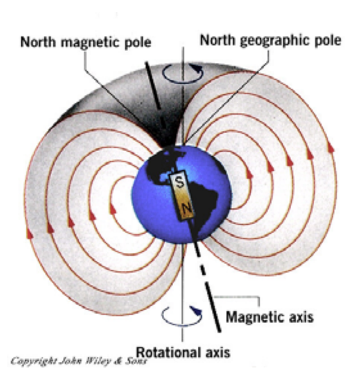

Figure 4.9: the earths magnetic field

5. Specifications

The next sections deal with the specifications of the several subsystems. The ground segment will be not covered in this chapter as it evolves from the spacecraft design and will be worked out in the latter phase. The specifications are not detailed down to numbers and values, as this will be subject for the next phase as well. Though they can be understood as the requirements from the preceding system level.

5.1 Spacecraft Specifications

5.1.1 Payload

<u>Optical sensor</u>

The sensor (a camera) will capture images on request and the OBC will store them in the memory. As those actions occur only from time to time and have very short duration, its influence on power usage is low. The mass will also be very little as there is a lot of technology already developed for the area of micro cameras e.g. for mobile phones. The sensor sits on the front side of the cube. The front side is maintained in a nadir fixed position, meaning that it will be oriented towards the earth's surface. It is the task of the ADCS subsystem to ensure a stable orientation.

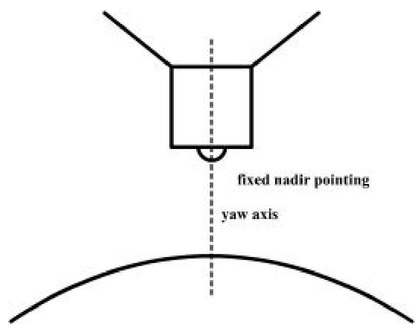

Figure 5.1: Nadir pointing of S/C

<u>Ka-band dish</u>

The dish will also be in use only for a short time compared to the mission lifetime. However, while in use it will probably consume a high amount of power. It has to be assured by the power subsystem that those requirements are met. The principle operation of the Ka-band transmission is to continuously send the payload information at a given time and duration. Since the satellite maintains in a stable position with the front side directed towards earth, the backside with the dish points into space. The beam width of the antenna will spread with distance. Due to the constant rotation around the earth, communication windows with geostationary relay satellites occur from time to time. It shall be ensured that a sufficient link budget can be created.

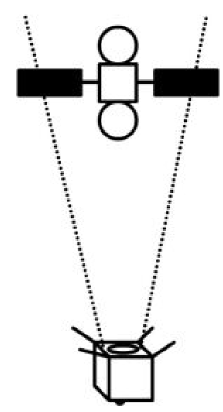

Figure 5.2: Ka-band link

5.1.2 ADCS

The attitude determination and control system (ADCS) is one of the most challenging parts of the spacecraft. It stabilizes the vehicle and orients it in the desired fixed nadir pointing position. This requires that the spacecraft determine its attitude by the use of sensors and then control it with the help of actuators. The satellite needs to be 3-axis stabilized.

5.1.3 Communications

The communications subsystem, also known as telemetry, tracking and command subsystem, is the interface between the satellite and the earth, or the satellite and other satellites. With its help data can be send from and towards the spacecraft. It modulates and demodulates carrier signals and uses unique frequencies for transmission. It is considered to use an omni directional antenna with isotropic distribution that operates in the L-band for amateur frequency.

5.1.4 Command & Data Handling

The level of autonomy is aimed to be very high with limited manual intervention from outside for redundancy only. The two distinctive types of data generated by the spacecraft are housekeeping information and the data generated by the payload. The bus mean power might be something about 250mW. To keep the size and mass for the electrical components by terms of magnitude lower than those of other missions the use Micro Electro Mechanical Systems (MEMS) and Micro-systems of the shelf (MOTS) technology is highly appreciated. As for the computer software the use of a higher language (in particular C++) is enforced to keep the system code clear and understandable. Yet for critical routines assembler programming will be used. The computer will have to handle a lot of task, working together with virtually all the other subsystems.

5.1.5 Power

Tasks of the power subsystem are to provide, store, distribute and control the spacecraft electrical power. For this satellite photovoltaic solar cells are the source of energy. The solar cells will give power as long as they are exposed to the sun. While the spacecraft passes the earths shadow energy has to be provided by a battery. The power subsystem manages not only the charging of the battery during daylight but also has to regulate the bus voltage. Moreover it has to control the electrical power generated at the cells to prevent undesired heating of the spacecraft. The cells will be placed on the exterior surfaces of the cube. This may provide at least 1W of power supply. Additionally the solar cells can also support the ADCS when used as a sun sensor.

5.1.6 Thermal

To ensure that all components, in particular the payload, maintain within their temperature limits a thermal control is necessary. Sources for heat are the sun, the earth and the heat production inside the spacecraft. The thermal control subsystem interacts with all the other subsystems but the power system characteristically has the greatest impact. To develop a thermal design the temperature boundaries of all spacecraft parts must be known. Out of the results from the thermal design a thermal model evolves. The thermal model calculations have then to be verified by solar balance and thermal vacuum tests.

5.1.7 Structure & Mechanism

The development of the structure is essentially defined by the CubeSat regulations. The mass for the frame structure shall be kept to a minimum while at the same time enough stiffness must be verified. It has to survive a range of mechanical loads without impairment. The use of Aluminum 7075 is suggested. The layout of the satellite is also based on the constraint to keep the center of mass within 2 cm of the geometric center. Also, there are a number of mechanisms on board the spacecraft. The antenna surely needs to be stored packed during launch. When in orbit, a mechanism finally has to deploy the antenna.

6. Conclusions

It was shown the overall layout of the COMPASS-1 system including the aspect of the product as well as the needed effort identification. The COMPASS-1 satellite is a pico satellite with a high vision. Whilst there is a lot of work expecting us (the student engineering team) we all share the confidence in mastering those together as a team of motivated and skilled engineering students.

7. References

Larson & Wertz 1996. *Space Mission Analysis and Design*. Kluwer Academic Publishers

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