Unmanned Solar Powered Airship Concept Evaluation

Critical Design Report

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Acronyms

APR Array Power Regulator

BCR Battery Charge Regulator

BJT Bipolar Junction Transistor

CDR Critical Design Review

COTS Commercial Of-The-Shelf

DM Development Model

ECSS European Cooperation for Space Standardization

EGSE Electrical Ground Support Equipment

EMI Electromagnetic Interference

EPS Electrical Power System

FM Flight Model

GaAs Gallium Arsenide

IC Integrated Circuit

IGBT Insulated Gate Bipolar Transistor

IRF Swedish Institute of Space Physics

ITPU Imaging and Tracking Payload Unit

ITU International Telecommunication Union

LTU Luleå University of Technology

MCC Motor Control and Communication

MEA Main Error Amplifier

MGSE Mechanical Ground Support Equipment

MPP Maximum Power Point

MPPT Maximum Power Point Tracking

MPPTU Maximum Power Point Tracking Unit

MSE Mechanical Structure and Envelope

NTC Negative Temperature Coefficient

OpAmp Operational Amplifier

PCB Printed Circuit Board

PDR Preliminary Design Review

PSA Pressure Sensitive Adhesive

PWM Pulse Width Modulated

SA Solar Array

SAR Solar Array Regulator

SPA Solar Powered Airship

SSC Swedish Space Corporation

TBD To Be Decided

TV Thermal Vacuum

U-SPACE Unmanned Solar Powered Airship Concept Evaluation

UAS Unmanned Aircraft System

UVP Under Voltage Protection

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Chapter 1

Introduction

Unmanned Solar Powered Airship Concept Evaluation (U-SPACE) is a student project at the Rymdcampus of the Luleå University of Technology (LTU) in Kiruna under the supervision of Kjell Lundin and Alf Wikström. It is supported by the Swedish Institute of Space Physics (IRF) and LTU. The goal of the project is to prove the concept of a small scale student-built unmanned Solar Powered Airship (SPA) powered by solar cells. The solar cells are mounted on a gas-filled envelope, with forward propulsion being achieved by propellers mounted on the same envelope. The airship communicates over two separate wireless connections with a ground station and a controller. These connections enable control over the airship, together with retrieval of housekeeping and scientific payload data. The scientific payload data consists of data from several sensors (magnetometer, GPS, etc.) and images taken by an onboard camera. On the ground station, the images and the sensor data are used to construct an aerial map.

The same concept of a SPA has attracted major interest in recent years [1, 2, 3, 4]. Such an airship could be used for a wide variety of applications, ranging from passenger and cargo transport [2] over scientific research [3] to planetary exploration [4]. These applications all benefit greatly from the advantages of a solar-powered airship: simple flight control, reduced fossil fuel consumption and access to long duration flights. Apart from these inherent strong points, other advantages of SPAs are the possibility for autonomous take-off and landing, the elimination of large infrastructures like airports and minimal weather constraints. Even though many researchers have investigated the possibilities of SPA's, few student-driven projects exist [5]. The above-mentioned advantages of SPA's and the fact that few student projects exist, were the main drivers for the creation of the U-SPACE project.

1.1 Hardware

The U-SPACE project hardware consists of four subsystems, each with their own set of smaller hardware units. The Mechanical Structure and Envelope (MSE) subsystem forms the main mechanical structure of the airship. It includes the gas-filled envelope, a payload bay and structures to mount both the solar cells and the motors with the propellers. The second subsystem, the Electrical Power System (EPS), is responsible for generating solar power, distributing this power to all other subsystems and storing the energy when necessary. The third subsystem, Motor Control and Communication (MCC), takes care of the forward propulsion of the airship by using propellers mounted on motors. The motors are controlled via a wireless connection, which is also the responsibility of this subsystem. The final subsystem, the Imaging and Tracking Payload Unit (ITPU), forms the scientific payload of the SPA. It consists of several different sensors (including a magnetometer, an accelerometer and a GPS) mounted inside the payload bay. The data from the sensors is processed with the help of a microcontroller. The payload bay also contains a camera which can take pictures from the ground and save them onboard. The sensor data is sent to the ground station via a separate wireless connection.

The ground station hardware forms a separate set of hardware required for the project. It consists of receivers for both wireless connections and a means to visualize the data obtained from the ITPU. It also contains a transmitter to control the motors of the MCC subsystem via a wireless link.

Block diagrams will be added in the final version...

1.2 Software

The software in the U-SPACE project is mainly built around the scientific payload unit (ITPU) and the ground station. The subsystem onboard the airship is able to read data from several sensors (magnetometer, GPS, accelerometer) and fuses the data to obtain more accurate information. This data can also be sent to the ground station via a wireless link, for which software is required as well. The third function of the ITPU is to take pictures of the ground. These pictures are saved onboard and can later be read out when the airship is retrieved.

The ground station software is required to receive sensor data from the airship. Apart from this function, the ground station software is also responsible for running the algorhythm that combines the sensor data and the images taken with the camera to obtain a complete aerial map of the surroundings.

The operational software modes are listed below:

1. Reading sensor data and fusing it
2. Taking pictures from the ground
3. Combination of mode 1 and mode 2

Chapter 2

Goals and Constraints

This chapter lists the goals and constraints of the U-SPACE project.

2.1 Project Goals

The goal of the U-SPACE project is to design, build and test a SPA for low altitude flying while supporting a scientific payload. Two future goals are implementing autonomous attitude control and altitude control of the airship.

2.2 Project Constraints

The constraints that have to be taken into account for this project can be divided into four categories: resources, functionality, environment and law. With regards to the resources, the following constraints can be identified:

- Limited time of one month and a half (part-time project work)
- Limited budget (10,000-12,500 SEK)
- Limited expertise in the field of airships

Two functional/technical constraints that have to be taken into account are:

- Electrical power is limited to 8 W.
- Mass is limited to 4.5 kg.

As this project will be executed during the months of April, May and June in the city of Kiruna, the environmental conditions are as listed below (using data for the month of May [6]):

- Average temperatures between -2 °C and 11 °C

- Typical wind speeds ranging from 1 m/s to 6 m/s (usually coming from the south west)
- Median cloud cover of 83 %
- Average probability of precipitation of 61 %
- Daily hours of sunshine between 17:38 hours and 22:45 hours
- Solar incidence angle of 46 ° (refer to document USPACE-PDR-PWR-A1)

Finally, two legal issues with regards to the project are presented below:

- The International Telecommunication Union (ITU) Radio Regulations [7] might have to be taken into consideration.
- The Swedish Transport Agency's regulations on Unmanned Aircraft System (UAS) [8] might have to be taken into account.

2.3 Expected Results

Referring to the project goals and constraints mentioned above, the expected result of the project is a small scale prototype of a SPA capable of:

- operating autonomously for 2 hours at peak power consumption,
- flying at an altitude between 1 m and 20 m,
- flying with a forward velocity between 0.5 m/s and 1 m/s,
- flying during daytime in sunny and calm weather conditions,
- supporting a scientific payload during its entire operating time.

2.4 Fault Tolerance Design, Safety Concept and Materials

Will be added in the final version...

Chapter 3

Mechanical Structure and Envelope

3.1 Functional and Technical Requirements

Will be added in the final version...

3.2 Mechanical and Structural Design

As was mentioned in the Preliminary Design Review (PDR), the initial mechanical design of the U-SPACE project included the development of a blimp (envelope) that would then accommodate the solar panels of the EPS, the cargo bay for the ITPU and the propelling system of MCC. An initial sketch of this concept is presented in figure 3.1.

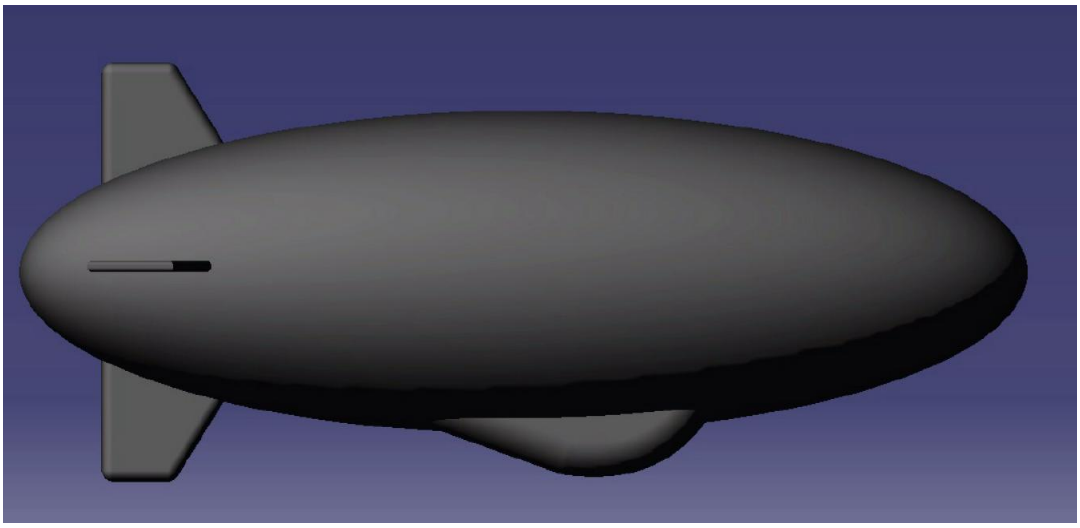

Figure 3.1 – *Initial 3D sketch of the airship*

This simplified view of the mechanical design shows that it included the total development of the envelope of the airship. The idea was to include the solar panels on the top, mounted on a wired mesh, with the cargo bay attached in the bottom together with the propelling system.

However, due to new developments in the project that included the introduction of an already built blimp (envelope), the focus of the mechanical design changed. The blimp to be used would be the TIF - 250 (Tethered Aerostats), shown in figure 3.2. This blimp has the capacity to lift a payload of about 2.5 kg, has a length of approximately 5 m and has a diameter (in the center) of about 1.9 m.

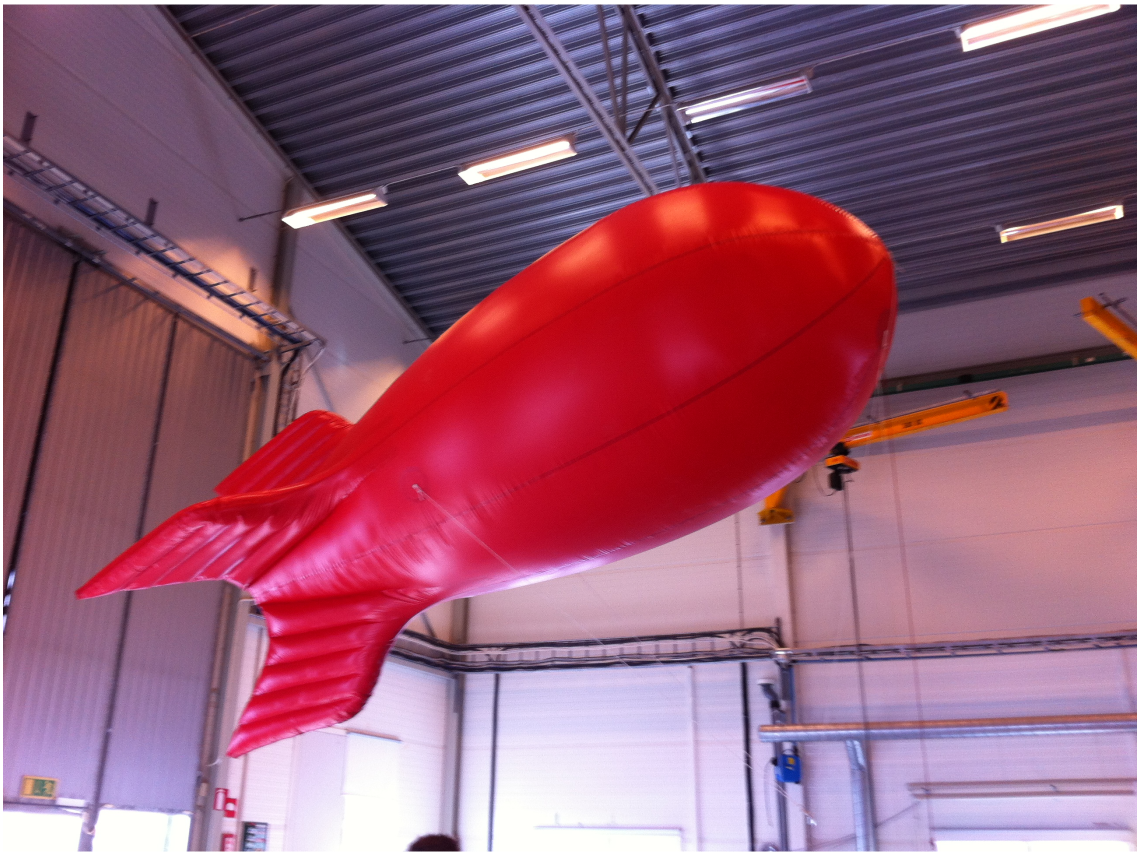

Figure 3.2 – *TIF - 250 Blimp*

This blimp serves the purpose of the U-SPACE project very well, as its use would allow to focus only on the construction of the support for the power system, the cargo bay (for the payload) and the integration of the propelling system. However, because it is a ready-built blimp with a purpose different than the one envisioned, it is not as lightweight as might be needed. Nevertheless, an effort will be made to include light structures in the integration of all the other systems in this airship.

3.2.1 Envelope

As it was already stated, the blimp to be used is a ready-built one. This blimp is normally used to accurately measure the wind direction. Nevertheless it will have to fit the purpose of the U-SPACE project, due to the lack of time to build a new envelope. This way, the envelope is constituted by the blimp itself.

3.2.2 Cargo Bay

The cargo bay is intended to accommodate both the payload and the electronics required for the purpose of the project. The main challenge in the construction of this cargo bay is the weight. It has to be lightweight (the total maximum weight of all the structures should be less than 1 kg) but at the same time rigid enough to resist some stress during the normal operation of the airship. To achieve this, balsa wood reinforced with carbon fibres was used. Figures of the expected final cargo bay design and of the current construction status are presented in figures 3.3 and 3.4, respectively.

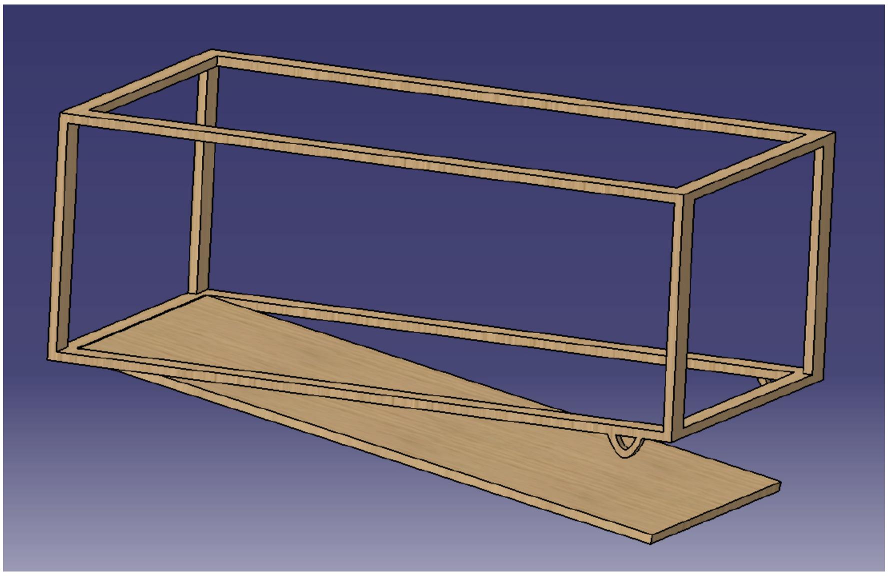

Figure 3.3 – *3D sketch of the cargo bay*

3.2.3 Power System

The biggest challenge of this project is to accommodate the power system, taking into account the maximum lift weight and also the power requirements that consequently influence the solar panel quantity and weight. Because different solar panels are still under test, it is still not decided how they will be mounted on the blimp. Nevertheless, the idea is to use a lightweight wired mesh that serves as a support to the solar panels, which are attached to the wires with carbon fibre. This mesh will then be connected to the blimp making use of 3 bands that will round the blimp, distributing the weight along the envelope. These bands will be made of fibre glass reinforced rubber tape. An idea of how the final product should look like is presented in figure 3.5.

3.2.4 Propelling System

The propelling system is to be integrated in a carbon fibre rod mounted on the top of the cargo bay. The 2 motors will be attached at the ends of the rod, outside the influence of the envelope and free to achieve their maximum aerodynamic capabilities. A hand sketch of this principle is showed in figure 3.6.

3.3 Future Developments

All the previously explained designs have to be built and tested. Conclusions have to be made and inputs from the other subsystems have to be taken into consideration. Only after a careful building of the different structures to accommodate all the required subsystems, it will be possible to check if the requirement of the maximum lift weight - the most important requirement - is achieved. For now, the 3D designs, the envisioned materials and previous experiences in the field give hope that this constraint will be surpassed.

The following steps should be to finish the construction of the cargo bay, accommodate the propelling system into it and then proceed with the construction of the wiring mesh and the consequent attachment of the solar panels.

Topics such as physical properties, structural and mechanisms analysis and mounting attachments will be discussed in the final version...

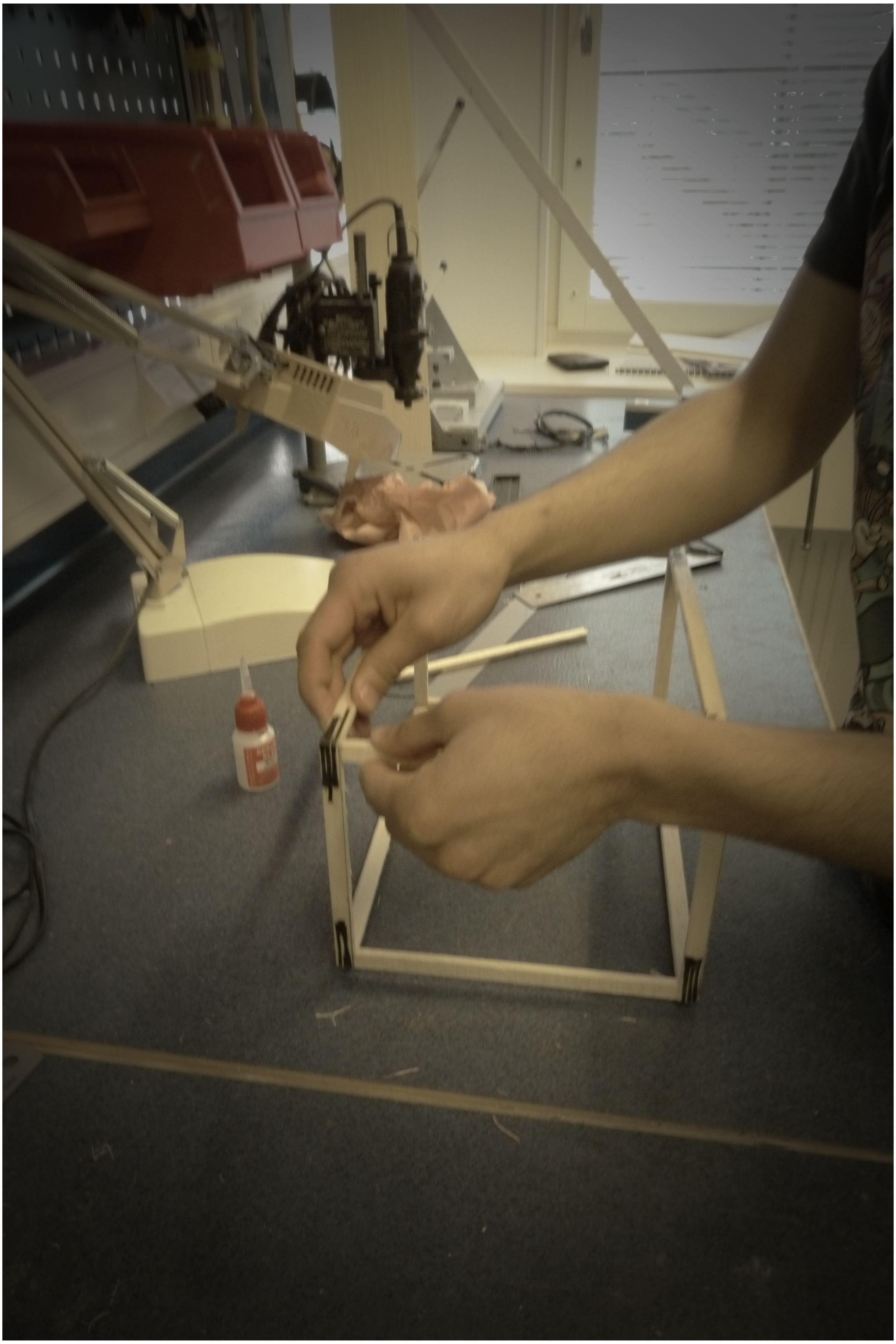

Figure 3.4 – *Initial construction phase of the cargo bay*

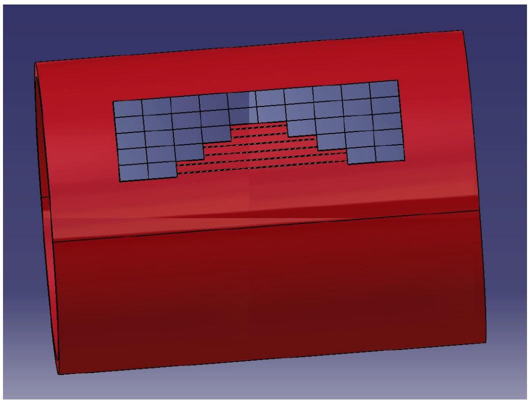

Figure 3.5 – *3D sketch of the integration of the power system*

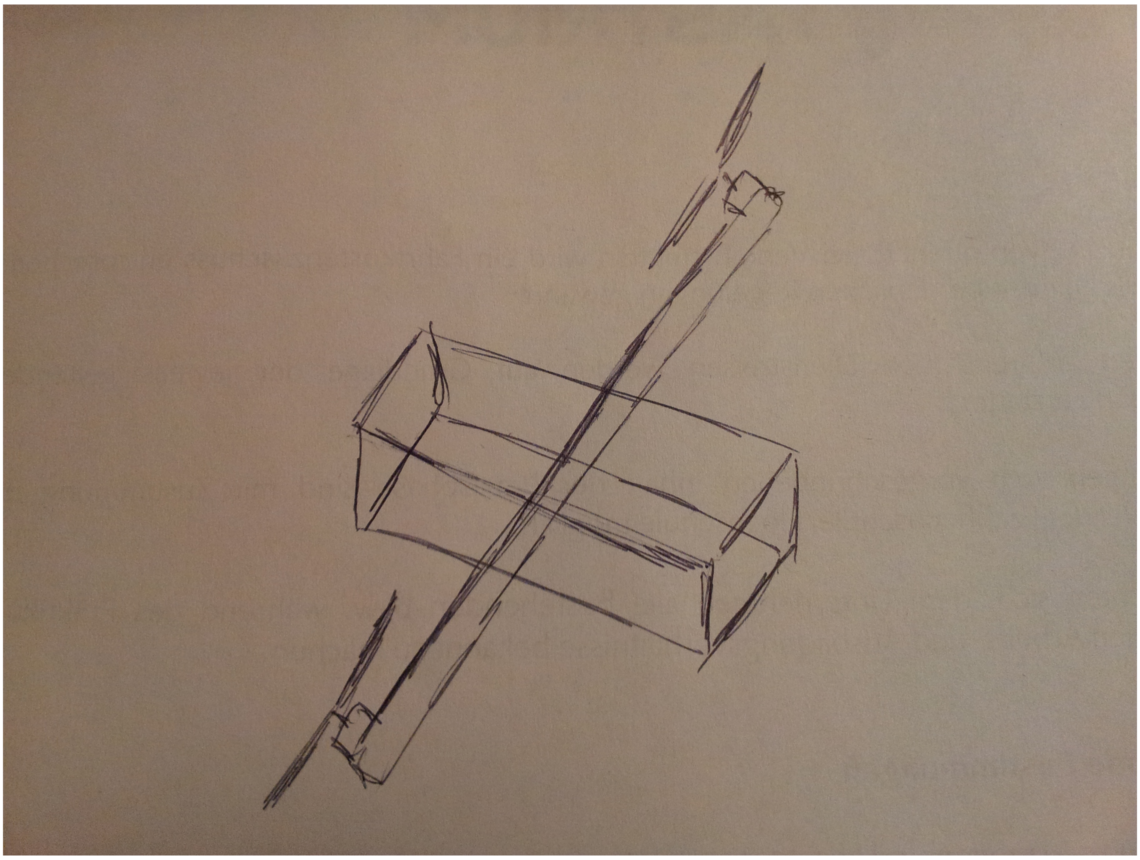

Figure 3.6 – *Hand sketch of the integration of the propelling system*

Chapter 4

Electrical Power System

4.1 Introduction

The EPS will provide sufficient power to the motors, communication system and payloads. Power is generated from solar cells and stored in batteries. DC-DC regulators are used to control the operating voltage of the solar cell and to provide regulated voltages to payloads and onboard computers.

4.1.1 Changes from PDR to CDR

The U-SPACE PDR for the EPS is documented in [9]. Table 4.1 lists the major EPS design changes between the PDR and the Critical Design Review (CDR) and the argumentations behind these design changes.

Table 4.1 – *U-SPACE EPS design changes from PDR to CDR*

Area of change	**Changed parameter**	**Argumentation for change**
Total power budget	increased to $> 40\,W$	Increased airship total mass and size
Solar cells	New part	Old solar cell was much heavier than listed in manufacturer datasheet due to a glass cover
Total system cost	increased to $> 12000\,SEK$	Increased power requirements and new light-weight solar cells are more expensive
Solar cell mounting	New part	New solar cell is flexible instead of rigid and can be mounted with Pressure Sensitive Adhesive (PSA)

4.2 Functional and Technical Requirements

4.2.1 Functional Requirements

Below are listed the primary functional requirements for the EPS:

- Provide adequate power to motors and payload
- Proof that flying on solar energy is possible i.e more power produced than consumed

Additional desired requirements are:

- Scalability to higher power levels
- Flexible and robust design, allowing flight in more extreme conditions (altitude, weather etc.)
- Provide adequate protection circuits for battery and loads
- Optimal design and high performance to increase power capability and minimize system mass

4.2.2 Technical Requirements

The EPS technical requirements are listed in table 4.2.

Table 4.2 – *Technical requirements for the EPS*

Minimum power output	$40\,W$
Maximum mass	$1000\,g$(including solar arrays)
Maximum cost	$5000\,SEK$[a]
Output voltages	$6.0 - 9.2\,V$(un-regulated), $5\,V$(regulated)
Maximum output current (worst case)	$10.5\,A$
Regulator phase margin	$60\,deg$
Regulator gain margin	$10\,dB$
Control loop bandwidth	$> 10\,kHz$
Operational temperature	$-20°C\,to + 25°C$
Battery capacity	$> 5\,Wh$

[a]Initial budget for 2 students.

4.2.3 Expected Performance

Table 4.3 – *Expected performance of the EPS*

Power conversion efficiency(overall)	$80 - 90\%$
Power output(overall)	$\sim 57 - 65\,W$
Battery capacity	$7.3\,Wh$
Mass	$\sim 910\,g$
Total cost	$\sim 12000\,SEK$[a]

[a]Solar cells are significantly more expensive than anticipated. A request for more funds is under preparation.

4.3 Critical Design

This section describes in more detail the EPS design. A simple block diagram of the EPS design is shown in Figure 4.1.

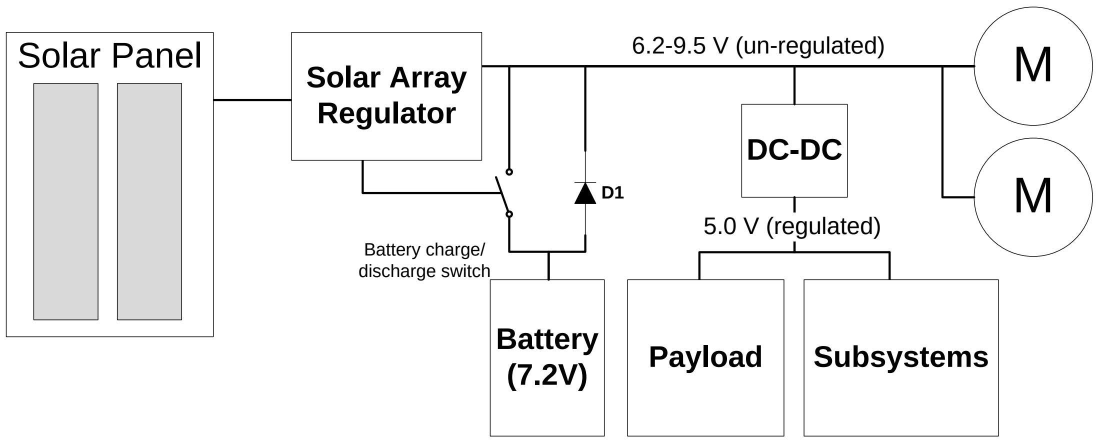

Figure 4.1 – *EPS simple blockdiagram*

4.3.1 Solar Array Design

As was mentioned in section 4.1.1, a new solar cell has been selected. This solar cell is shown in Figure 4.2 and Table 4.4 lists the important specifications for this cell.

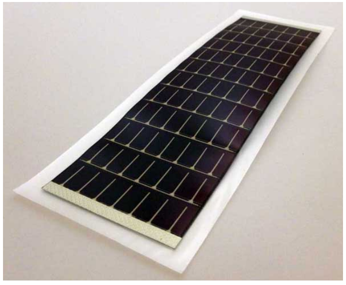

Figure 4.2 – *Chosen solar cell*

Table 4.4 – *Specifications of chosen solar cell*

Nominal output current	$100\,mA$
Nominal output voltage	$7.2V$
Nominal output power	$0.72\,W$
Dimensions	$270\,mm\ \times\ 90\,mm\ \times\ 0.2\,mm$
Weight	$7.6\,g$
No. of required cells 100[a]	
Total solar panel area	$2.43\,m^2$ (assuming $100\,\%$ fill factor)

[a] [10] offers good discount for +100 units order

The solar panels will be configured with two series-connected solar cells thus having an output voltage of:

$$V_{panel,out} = 14.4\,V \tag{4.1}$$

4.3.2 Battery Design

Two Panasonic PA-L60.K02 [11] Li-ion batteries are used. The battery has the following important specifications:

Table 4.5 – *Specification of chosen battery*

Chemistry	Li-ion
Nominal voltage	$3.6\,V$
Capacity	$1.03\,Ah$ / $3.61\,Wh$
Weight	$25\,g$
Dimensions	$56\,mm\ \times\ 34.2\,mm\ \times\ 5.8\,mm$
Maximum charge current	$970\,mA$
Maximum discharge current (continuous)	$1.455\,A$

Future Recommendations The chosen type of Li-ion battery supports only a relative low charge- and discharge rate of about $1\,C$. For bigger battery capacity and higher loads, it is recommended to use a battery like [12] which provides much higher discharge rates ($> 20\,C$) and also cheaper price per Wh. Only disadvantage is a mass increase of around $15 - 25\%$.

Battery Charge Regulator

From the battery datasheet, maximum charge current is $I_{REG} = 970\,mA$. From the Battery Charge Regulator (BCR) datasheet, the minimum current sense resistor value is calculated as

$$\begin{aligned} R_{sense} =& \frac{V_{FCS}}{I_{REG}} \\ R_{sense} =& \frac{120\,mV}{970\,mA} = 123\,m\Omega \end{aligned} \tag{4.2}$$

The required thermal rating of the pass transistor is calculated as

$$P_{max} = (V_{in,max} - V_{bat,min}) \cdot I_{charge} = (9.5\,V - 5.5\,V) \cdot 970\,mA = 3.88\,W \tag{4.3}$$

Battery Temperature Monitoring

The BCR chip includes a temperature monitoring feature. The battery is rated, in charge-mode, to temperature in the interval $10 - 45°C$. The maximum allowed temperature is set slightly lower to $40°C$. The Li-ion battery has a build-in Negative Temperature Coefficient (NTC) thermistor with $B = 3980\,K$ and $R_{25} = 10k\,\Omega$. The required restance values of the temperature control resistors are determined from the BCR chip datasheet as

$$\begin{aligned} R_{cold} &= R_{25} e^{B(\frac{1}{T} - \frac{1}{T_0})} = 10\,k\Omega e^{3980\,K(\frac{1}{283\,K} - \frac{1}{298\,K})} = 20.3\,k\Omega \\ R_{hot} &= 10\,k\Omega e^{3980\,K(\frac{1}{313\,K} - \frac{1}{298\,K})} = 5.3\,k\Omega \\ R_{T1} &= 2\frac{R_{cold}R_{hot}}{R_{cold} - R_{hot}} = 14.2\,k\Omega \\ R_{T2} &= 2\frac{R_{cold}R_{hot}}{R_{cold} - 3R_{hot}} = 47.8\,k\Omega \end{aligned} \tag{4.4}$$

Battery Discharge Current Limiter

The selected MOSFET has a typical gate threshold voltage of $V_{Gth} = 550\,mV$. The chosen Bipolar Junction Transistor (BJT) has a typical collector-emitter voltage drop of $V_{CE} = 120\,mV$. The battery is rated for a maximum discharge current of $I_{discharge} = 1.455\,A$. The required current sense resistor is then calculated as

$$\begin{aligned} V_{sense} &= V_{Gth} - V_{CE} = 550\,mV - 120\,mV = 430\,mV \Rightarrow \\ R_{sense} &= \frac{V_{sense}}{I_{discharge}} = \frac{430\,mV}{1.455\,A} = 295\,m\Omega \end{aligned} \tag{4.5}$$

The exact required resistance must be determined by testing the precise parameters of the discrete components.

4.3.3 Maximum Power Point Tracking Regulator

In [9] it was decided to use a Maximum Power Point Tracking Unit (MPPTU) for the Array Power Regulator (APR) due to its high efficiency and robustness to changing environmental constraints.

In first step, only the DC-DC converter will be implemented. When time and resources allows the Maximum Power Point Tracking (MPPT) part will be added. A simple buck DC-DC converter topology is used, comprising a transistor, free-wheel diode, inductor and output capacitor. When the full MPPTU is implemented, it will operate in three different operation regions:

- Battery discharge MPPT - when the solar array input power is insufficient to cover the load power demand, the battery is slowly discharged in order to maintain the output voltage.
- Battery charge MPPT - when the solar array input is greater than the load power, the excessive power is used to recharge the battery.
- Input power limitation - when the battery is fully charged, the regulator will operate the solar array at a non-optimal voltage, thus limiting the input power to keep the output voltage constant. The extra potential input power is dissipated as heat externally on the solar arrays.

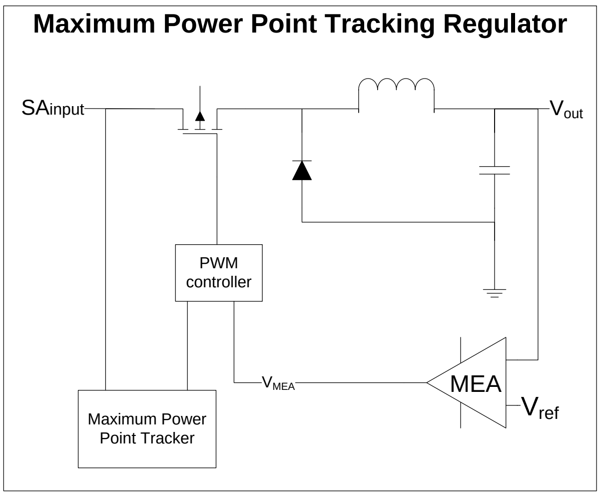

Figure 4.3 – *MPPT regulator diagram*

Mainbus Under Voltage Protection

The power from battery and solar cells is limited. It is thus possible that the motors will try to draw more current than what can be delivered. If this happens, the output capacitor of the APR will quickly discharge and the main output voltage drops out. To prevent this situation, an Under Voltage Protection (UVP) circuit is added. This is implemented using an $STN888$ PNP BJT along with two resistors, $R3$ and $R4$ as shown in Figure 4.4. When the main output voltage is around $6.2\,V$ the Base-Emitter voltage drop is close to $1.2\,V$ and the BJT is fully conducting and effectively works as a short circuit. If the output voltage drops significantly below $6.2\,V$ the BJT will begin to decrease the output current until the output voltage stabilizes. The current gain of $STN888$ is about 100, hence to allow an maximum output current of $10\,A$, the resistors $R3$ and $R4$ must be designed to pass $100\,mA$ at $6.2\,V$ output voltage. To minimize efficiency it is important that the forward voltage drop of the BJT is kept as low as possible.

Further Recommendations It is hard to find suitable BJTs rated for much more than $5\,A$. If the power output is increased in future designs, it is suggested to either parallel connect several BJTs however this might cause issues with thermal runaway. Alternatively high current Insulated Gate Bipolar Transistors (IGBTs) can be used, however they have higher forward voltage drops and thus they are more suitable for a design with a higher output voltage.

4.3.4 Complete EPS Diagram

The complete EPS diagram is shown in Figure 4.4. For providing the $5\,V$ regulated voltage to the payloads, Commercial Of-The-Shelf (COTS) DC-DC regulator(s) are used. The battery charging/discharging is controlled by the Solar Array Regulator (SAR).

4.3.5 External Interfaces

The interfaces of the EPS external are listed in table 4.6.

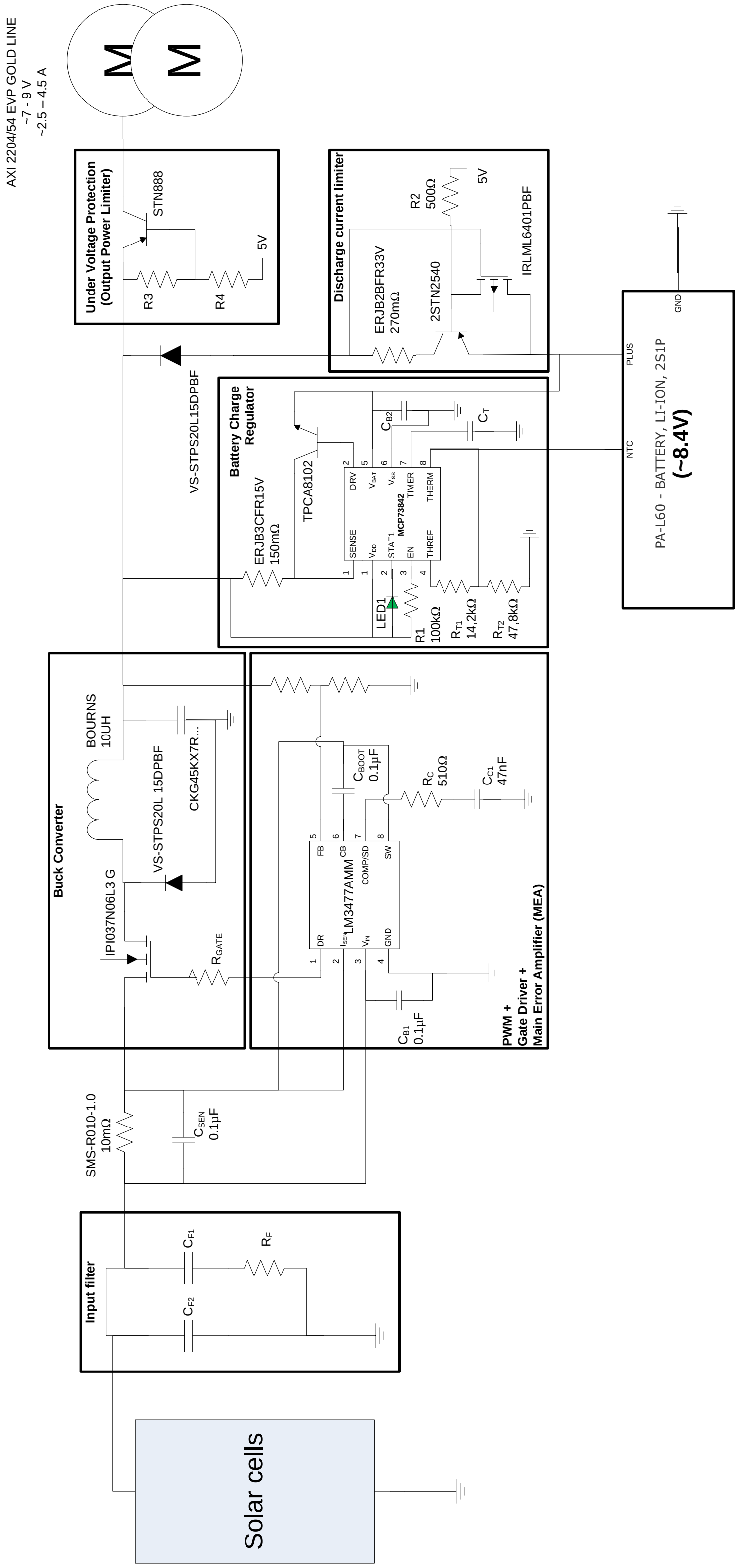

Figure 4.4 – *EPS detailed block diagram diagram*

Table 4.6 – *External interfaces*

External interface	Implementation
Solar cells mounting	PSA
DC-DC regulators	Mounted on PCB which sits in system housing. Thermal contact points should be included, to remove internal heat dissipation.
Battery telemetry	Analog signals to Microcontroller
Mounting of batteries	To Be Decided (TBD)
Supply voltages	$6.0 - 9.2\,V$ (unregulated) and $5.0\,V$(regulated)

4.3.6 Telemetry and Telecommands

The required/recommended telemetry and telecommands, EPS , are listed in table 4.7.

Table 4.7 – *Telemetry and telecommands*

Telemetry	Data rate/frequency	Data size
Battery voltage	Every 30 sec	2 bytes
Battery temperature	Every 5 sec	2 bytes

4.4 Test and Verification of Design

4.4.1 Preliminary Verification of Design

Will be included in the final version...

4.4.2 Design Models and Verification Methods

PSpice Simulations

PSpice transient and average simulation models of the SAR will be created. These will help in the design and testing of the regulator performance and system stability during transient loading.

Development Model

A Development Model (DM) will be build using self-made "mini-mount" pads and mainly surface-mount components, to minimize parasitic effects. System stability will be tested using a Network Analyzer and MPPT performance will be tested in a Thermal Vacuum (TV) chamber cycling the solar array temperature.

Flight Model

If time allows, a dedicated Flight Model (FM) will be build, using a custom designed Printed Circuit Board (PCB) schematic layout. An optimized PCB layout will minimize the system mass and size while maximizing the efficiency and system robustness.

4.5 Resources and Scheduling

4.5.1 Main Tasks

Will be included in the final version...

4.5.2 Parts List and Costs

Will be included in the final version...

4.5.3 Electronics Ground Support Equipment (EGSE)

Will be included in the final version...

Chapter 5

Motor Control and Communication

The Motor Control and Communication subsystem is responsible for providing sufficient thrust to the airship for its movement and communication from ground. Two motors with propeller will be used for controlling the flight of the airship. Communication will be handled with commercial transmitters/receivers operating at 2.4 GHz.

5.1 Functional and Technical Requirements

Below are listed the primary functional requirements for the MCC:

5.1.1 Functional Requirements

- Reliable communication between ground controller (transmitter) & airship (receiver)
- Independent speed control for each of the motors and provision of sufficient thrust to the airship
- Operation of the airship from ground

5.1.2 Technical Requirements

MCC's technical requirements:

- Maximum power comsuption: 50 to 60 W Approx.
- Mass: 50 g Approx with mountings
- Maximum cost: 2500 SEK
- Input Voltage: 3.8 V Approx

- Transmission frequency: 2.4 GHz
- Receiver channels: 6

As it was decided to use the blimp from ESRANGE instead of the structure that was supposed to be built by MSE, the whole system had to be re-designed. The main reasons were the dimensions of the blimp and the limitation on the total weight it is able to carry. This required for the MCC to use more powerful and efficient motors since the power system was affected as well, while the transmitter/receiver system remained unchanged.

Brushless motors were chosen as they are known to be more powerful and lighter at the same time ($38g$) and dimensions of $27.6 \times 11mm$ (see figure 5.1). However this motors require a bit more current than the ones that were chosen originally. Therefore suitable ESC were chosen which are able to supply a maximum current of 10 A.

Figure 5.1 – *Motors purchased from http://www.rcflight.se*

5.1.3 Expected Performance

- Motor efficiency: 77 %
- RPM (for each motor): 1400 RPM/V

5.2 Design of the System

The functioning of the MCC subsystem is shown in figure 5.2. The transceiver consists of 2.4 Ghz transmitter and receiver. The receiver gets the motor speed control commands to the ESC which in turn actuate the motor to the desired speed.

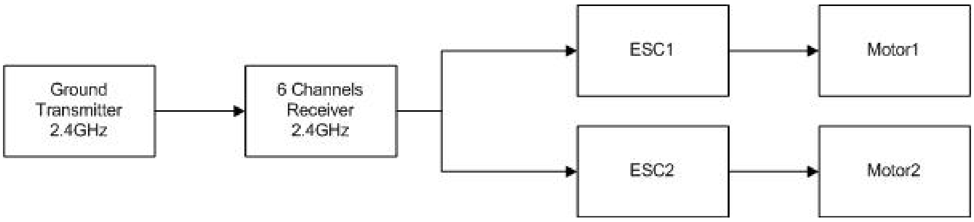

Figure 5.2 – *Block Diagram of the MCC Subsystem*

5.2.1 Trade-Off Analysis of Concepts

For the tranceiver system the available options are to use

- A 72 Mhz transceiver system that uses Amplitude/Frequency Modulation
- A 2.4 Ghz tranceiver system that uses Spread Spectrum Technology

Parameter:	**2.4 Ghz Tranceiver**	**72 Mhz Tranceiver**
Frequency Used	2.4 Ghz	72 Mhz
Crystal Used	No	Yes
Change in Frequency	On next power up	By changing the crystal
Ability to transmit through obstacles	Weak	Very Good
Band Width	Wide	Narrow
Date Rate	High	Low
Power Usage	Less	More
RF Noise Immunity	Very Good	Less

Table 5.1 – *Trade off analysis*

It is clear from the Table 5.1, that a 2.4 GHz Tranceiver System is a clear winner for chosen application. The only disadvantage of using a 2.4 Ghz tranceiver system is that the receiver should have really good batteries and the voltage should be maintained at a paritcular level. The reason being that there are small processors in the transmitter and receiver that carry out many complex calculation every second without mistake. These processors require constant steady supply of current to work properly. If there is an interruption in the supply current of the receiver then there would be problems with the communication channel.

The speed of the motor can be controlled by the following methods:

- Use a commercial off the shelf Electronic Speed Controller(ESC) for each motor.

- Build a Motor Speed Controller using a microprocessor.

The primary advantage of using commercial off the shelf Electronic Speed Controller is the ease of use. This would reduce the development cycle to a large extent. The disadvantage of using it is no scalability i.e. function like autonomous control and telemetery and telecommanding are not possible.

5.2.2 Argumentation for Chosen Concept(s)

The 2.4 Ghz tranceiver system would be used for communication. The transceiver used 2.4 Ghz frequency band and uses the spread spectrum technology for transmission of signals. This helps in removing all interfering frequencies caused by other electronic equipments and this helps in having a better communication channel. The other major advantage of using this tranceiver using spread spectrum technology is that the communication channel would not be affected even by someone using the same frequency band.

Commercial off the shelf Electronic Speed Controllers would be used to control the speed of the motors because of time constraint in the project. If time permits it would be desirable to build a speed controller with the help of microprocessor.

5.2.3 Feasibility Study of Concept(s)

The important part in the communication part of the subsystem is deciding upon tranceiver system which would allow bidirectional control of the motor. Since tranceiver is commercial of the shelf, configuring it would be a short task. Again in the case of motor speed control, choosing the correct ESC and motor combo is the most important task and given maximum time after which assembly is relatively easier and less time consuming.

Chapter 6

Imaging and Tracking Payload Unit

The Imaging and Tracking Payload Unit (ITPU) is the scientific payload of the airship, and is in general independent of the airship's control system, but uses the airships power system. However it would be possible in an extended version to also incorporate a controlling interface and connect the motor ESCs for the motor control to the computer of the ITPU.

The purpose of ITPU is to take aerial images from different positions, acquire accurate position and attitude data and use those combined information to create aerial image maps.

The system is further divided into the following parts:

- Attitude determination: Usage of advanced data fusion method to facilitate GPS, Gyro, Accelerometer and Magnetometer information, to extract accurate position and attitude information together with reasonable error estimates.
- Imaging system: A megapixel resolution webcam will provide images in regular timesteps in the order of a second. The image data will be saved on a SD memory card together with attitude information for offline processing.
- Communication system: Attitude data and spacecraft telemetry will be transmitted to ground.
- Image processing software: Image matching and evaluation will be done on a standard PC after payload recovery.

6.1 Functional and Technical Requirements

- Measure absolute and accurate position and pointing angles.
- Take images in regular steps and save them together with attitude data.
- Receive and execute basic telecommands such as image capture start/stop.
- Send basic telemetry data such as position.
- Combine single image captures to a large area map.
- Operate in open air environment up to 500 m over ground. In U-Space the module will only fly to a height of a few 10s of meters. However it should be used in higher altitudes for later applications.
- Operate at 5 V unstabilized input voltage at a maximum power consumption of 2.5 W.
- Store at least 1000 medium-resolution images.

6.2 Electronic components

- Board computer
- Accelerometer
- Magnetometer
- Gyroscope
- GPS-receiver
- Transmitter/Receiver
- Camera

Board computer

For reading the sensors, communicating with the ground station and saving images from the camera an embedded system which provides all necessary interfaces and enough computing power to handle comparably large data streams from the camera was needed. It was chosen to use the BeagleBone, but only the BeagleBoard was delivered which is a related predecessor and lacks some features.

The BeagleBoard is a microcontroller board running a TI OMAP3530 ARM Cortex-A8 system on a chip (SoC). It provides 256 MB RAM and several high and low level interfaces. For this project the main interfaces used are the I2C and UART for communication with the sensors (gyroscope, magnetometer, accelerometer) and the GPS-receiver and radio-transmitter module (E-TAG) respectively. The camera The used high level interface is the USB-host adapter to connect the camera to. The operating system with the control program as well as the image files are stored onto an 8 GB class 10 sd-card. The needed supply voltage for the BeagleBoard is 5 V. The voltage of the pins on the expansion header is 1.8 V.

Sensors

For determining the position and attitude the LSM303DLM [13] combined magnetometer and accelerometer and the ITG-3200 triple-axis gyroscope [14] from sparkfun were used. Both sensors have been used during the CanSat-project in Würzburg with decent results. They communicate via an I2C interface with the main board at 3.3 V. For receiving GPS information an E-TAG device developed by Esrange was used. It is connected via a serial line interface with the main board. It also provides a transmitter module for communicating with the ground station.

Camera

As high quality embedded industrial cameras are very high priced, a consumer webcam with a resolution of several megapixels will be connected to the USB-port of the main board. It is intended to buy a camera which is supported by the Linux operating system running on the main board.

6.3 Software environment

The BeagleBoard is equipped with an 8 GB sd-card. A debian based Linux operation system is installed onto the card providing the environment, libraries and drivers for the program to run. As compared to the BeagleBone the BeagleBoard lacks pull-up resistors on its I2C interface which produced problems with Linux kernel the standard kernel for this board came without the possibility to enable the I2C controller. Therefore an own version of the Linux kernel had to be compiled for the BeagleBoard in order activate the I2C device on the expansion header.

The program is divided into several threads. One thread is responsible to get the newest sensor data from the accelerometer, magnetometer and gyroscope from the I2C interface and fuse them to accurate position and attitude representations. It is running at a comparably high frequency (>50 Hz, the final frequency is not defined yet). More about the algorithm for sensor fusing is explained in section ????. A second thread is polling for new GPS data from the E-TAG via serial line. As the GPS-chip only updates the positional data around once per second this thread can run at a much lower frequency. A third thread is responsible to control the camera. If it is active it will shoot a picture every second and save it to the sd-card. And finally two threads will be handling sending telemetry data to and receiving basic commands from the groundstation.

Due to lack of time a standard kernel was used which is not hard real-time capable. Nevertheless it still has the possibility to use preemptive scheduling which should give a high enough accuracy, but it should be noted that in future developments it could be beneficial to use a real-time Linux kernel.

6.4 Image processing

Will be included in the final version...

6.5 Attitude Determination System

The Attitude Determination System (ADS) measures and estimates position and pointing direction of the payload system. This is crucial for the further use of recordet images, as it provides the reference system and relative alignment of the taken images towards each other.

In order to produce high-accuracy attitude estimates and compensate for disadvantages of certain sensor types such as drift and noise, we chose to use a variety of sensors and fuse their information to a combined information. The facilitated sensors will be (see figure 6.1):

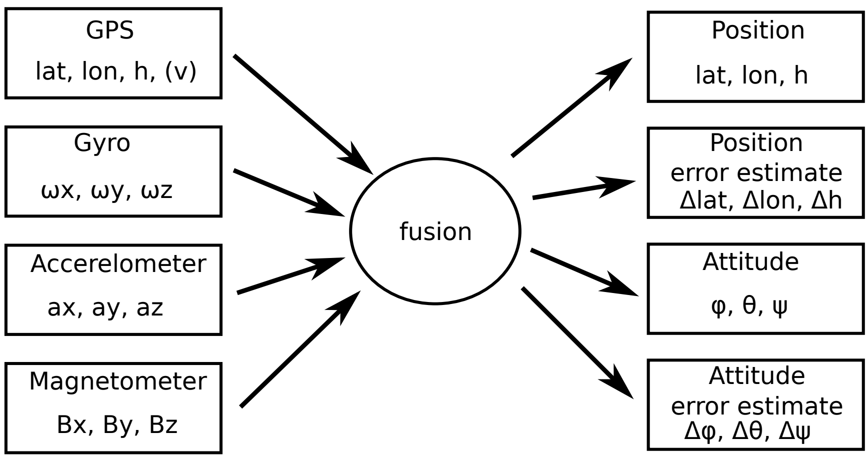

Figure 6.1 – *Attitude Determination System overview*

- GPS receiver: Provides absolute position values, but has much high-frequency noise
- Gyroscope: Provides accurate relative pointing direction, but has drift.
- Accerelometer: Provides absoulte pointing relative to the horizon (gravity) and linear acceleration.
- Magnetometer: Provides absolute pointing relative to the earth's magnetic field.

Combined all together, these sensors provide complete information about the module's attitude. As a fusion method we will use well-understood algorithms, such as the extended Kalman filter.

The fused information will be updated in real-time and stored together with each image snapshot.

For development of the software, a simulation module is being written that feeds simulated measurement data into the fusion algorithm. By this the performance can be quantified and development gets much faster than with waiting for actual measurement data.

The fusion algorithm being developed and implemented in C++ will use a Kalman-like approach with least-square estimators for an optimized estimation of position and attitude combined. In a first simpler appoach, we treat position and attitude independetly, which is less accurate but more robust as the system is being developed.

6.6 Electrical Circuits

As compared to the BeagleBone the delivered BeagleBoard's voltage at the pins of the expansion header is only between 0 V and 1.8 V but the expected voltage at the supply and the I2C interface for the sensors is 3.3 V additionally to the external pull-up resistors on the I2C interface also voltage level converters have to be used.

More information will be included in the final version...

Chapter 7

Thermal Interfaces, Pyrotechnics and Electromagnetic Compatibility

Will be included in the final version, but was omitted for now as they are not relevant for this project...

7.1 Thermal Interfaces

7.2 Pyrotechnics Interface

7.3 Electromagnetic Compatibility

Chapter 8

Test and Verification of Design

This chapter describes the test procedures of the U-SPACE project. Objectives and responsibilities are introduced in section 8.1,together with the main test procedures. Section 8.2 describes the different test matrices of the subsystems.

8.1 Design Verification Plan

8.1.1 Objectives and Responsibilities

Will be included in the final version...

8.1.2 Verification By Test

To test and verify the proposed design concepts throughout the project, four methods are considered [15], as listed in table 8.1.

Table 8.1 – *Design verification methods*

Method	**Description**
Testing	Monitoring of system performance and functionality in a simulated test environment.
Analysis/Simulation	Theoretical calculations and simulations. Also includes verification by similarity, i.e. previously used solution concepts.
Review of Design	Using records, drawings, schematics, etc. that unambiguously show fulfilment of the system requirements
Inspection	Visual inspection of hardware/software for good workmanship as well as compliance to industry/design standards

To test the complete SPA, a DM will be built and subjected to flight testing. A 3-4 week launch campaign is scheduled for the start of autumn. The planned launch site is the old balloon launch site at IRF near the LTU Rymdcampus or a location at the Esrange Space Center (in cooperation with the Swedish Space Corporation (SSC)).

8.2 Subsystem Test Matrices

Will be included in the final version...

Chapter 9

Ground Support Equipment

This chapter describes the required electrical ground support equipment and mechanical ground support equipment for the U-SPACE project.

9.1 Electrical Ground Support Equipment (EGSE)

During flight testing of the DM, the following Electrical Ground Support Equipment (EGSE) are required:

- A power supply to charge the EPS batteries before flight.
- A ground station (depending on the final design of the communication system and requirements for telemetry/telecommand).

More information will be included in the final version...

9.1.1 Concept

9.1.2 Hardware Description

9.1.3 Software Description

9.2 Mechanical Ground Support Equipment (MGSE)

Developing, building and testing the SPA will require the following Mechanical Ground Support Equipment (MGSE):

- During flight test a safety system is required to prevent the airship from flying beyond the flight test perimeters in case of failing attitude control. This could be implemented using a simple cable/rope or a similar system.
- Facilities at test locations for on-site fuelling of the envelope gas, i.e. gas tanks, valves, tubes etc.

- Storage facility at IRF/LTU Rymdcampus, for the SPA DM, components and materials. This storage facility should be large enough to accommodate and transport the large SPA structure.

Chapter 10

Project Management

This chapter describes the different aspects of the project management.

10.1 Organisation and Responsibilities

10.1.1 Key Personnel and Responsibilities

Will be included in the final version...

10.1.2 Functional Organigram

Based on the expertise of the team members a functional organigram was defined. This structure is shown in figure 10.1.

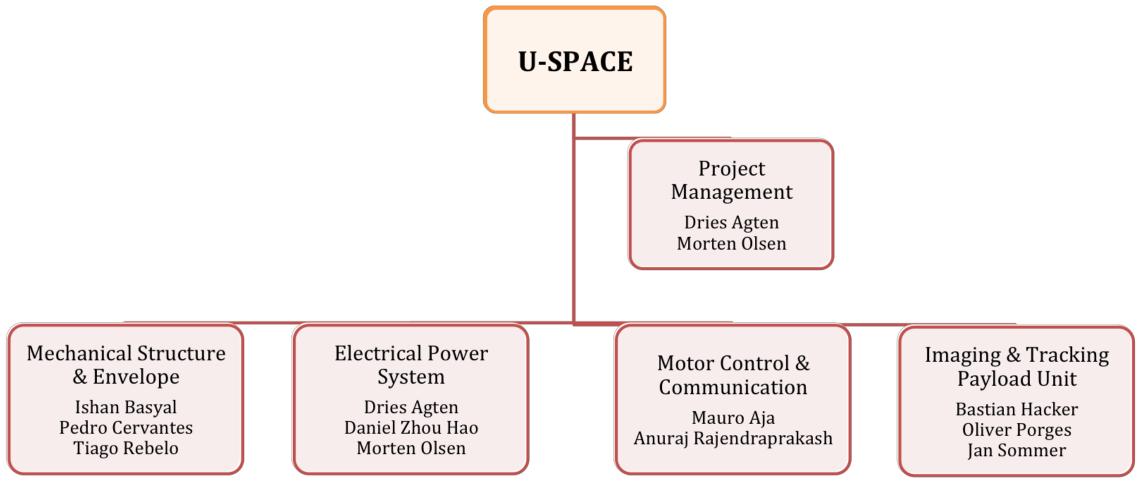

Figure 10.1 – *Functional organigram*

The background of each team member can be found in table 10.1 below.

Table 10.1 – *Background of team members*

Name	Background
Dries Agten	M.Sc. Eng. - Nanoscience & Nanotechnology
Mauro Aja	B.Sc. Eng. - Electronic and Computer Engineering
Ishan Basyal	B.Sc. Earth and Space Sciences
Pedro Cervantes	B.Sc. Eng. - Aeronautical Engineering
Bastian Hacker	B.Sc. Physics
Daniel Zhou Hao	B.Sc. Eng. - Aerospace Engineering
Morten Olsen	B.Sc. Eng. - Electrical Engineering
Oliver Porges	B.Sc. Cybernetics and Measurement
Anuraj Rajendraprakash	B.Tech. Electronics Engineering
Tiago Rebelo	B.Sc. Eng. - Aeronautical Engineering
Jan Sommer	B.Sc. Computational Science

10.1.3 Support Facilities

The U-SPACE project is supported practically, financially and technically by LTU. IRF and Esrange both provide technical assistance. The practical support from LTU consists of the availability of tools and specific rooms (e.g. mechanical workshop or electronics laboratory). Also component orderning (see section 10.2.3) is the responsability of LTU. The financial support is discussed in section 10.3.

The technical help of all three support entities consists of guidance regarding the components, support during the fabrication and assistance with the future testing procedures.

10.2 Relation With Support Facilities

10.2.1 Reporting and Monitoring

During the entire project, the team is monitored by Kjell Lundin (IRF) and Alf Wikström (Esrange). The team and the supervisors have weekly status meetings, in which all current issues are identified, discussed and solved. Reports to the supervisors are discussed in the next subsection.

10.2.2 Reviews

Will be included in the final version...

10.2.3 Component Ordering

LTU helps the team with the ordering of all components, both national and international. The procedure include component selection by the team, followed by approval of the supervisors and then the final ordering of the components by LTU.

10.3 Financing

Will be included in the final version...

10.4 Schedule and Milestones

Will be included in the final version...

10.5 Configuration Control

Will be included in the final version...

10.6 Deliverables

Will be included in the final version...

10.6.1 Hardware and Software

10.6.2 Documentation

10.6.3 Deliverable Items and Build Standard

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