Unmanned Solar Powered Airship Concept Evaluation

Critical Design Report

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Acronyms

EGSE Electrical Ground Support Equipment

EPS Electrical Power System

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

MGSE Mechanical Ground Support Equipment

MSE Mechanical Structure and Envelope

SPA Solar Powered Airship

SSC Swedish Space Corporation

U-SPACE Unmanned Solar Powered Airship Concept Evaluation

UAS Unmanned Aircraft System

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Chapter 1

Basic LaTex Commands

This section provides some basic useful LaTex commands. For further reference, search on Google where you will find plenty of useful LaTex blogs. **Remove this chapter later on...**

1.1 Figures

This is a figure example:

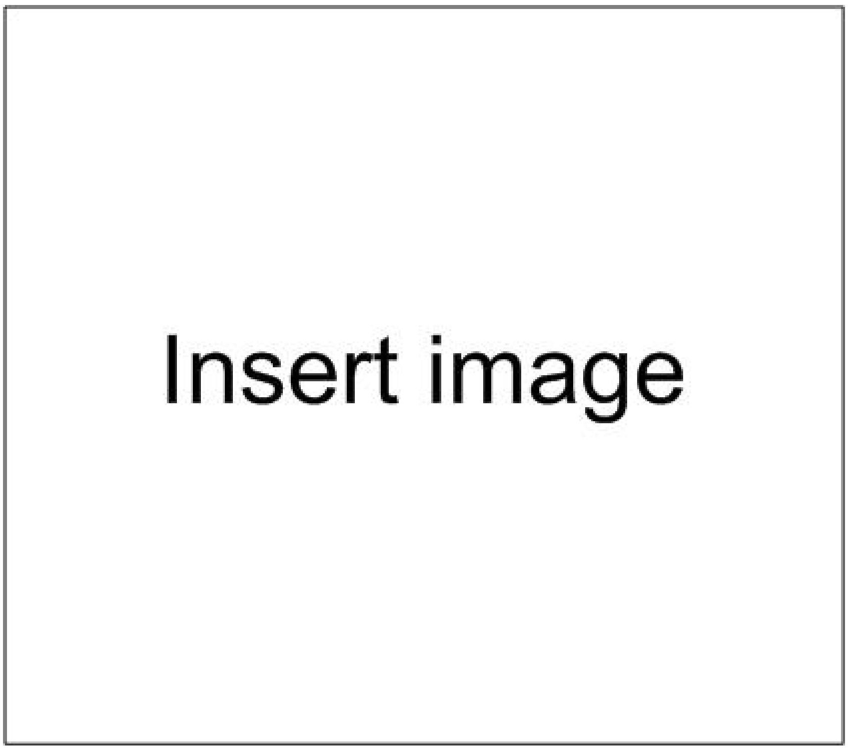


Figure 1.1 – *This is a figure caption*

You can also place figures side-by-side. An easy way is to use a "minipage" environment:

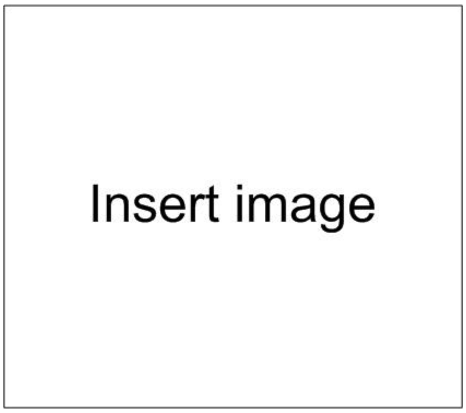


Figure 1.2 – *This is a figure caption*

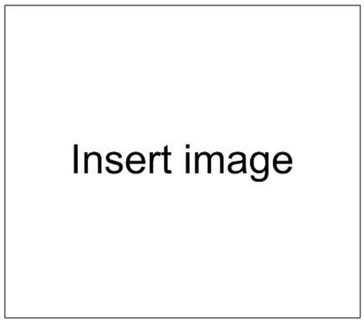
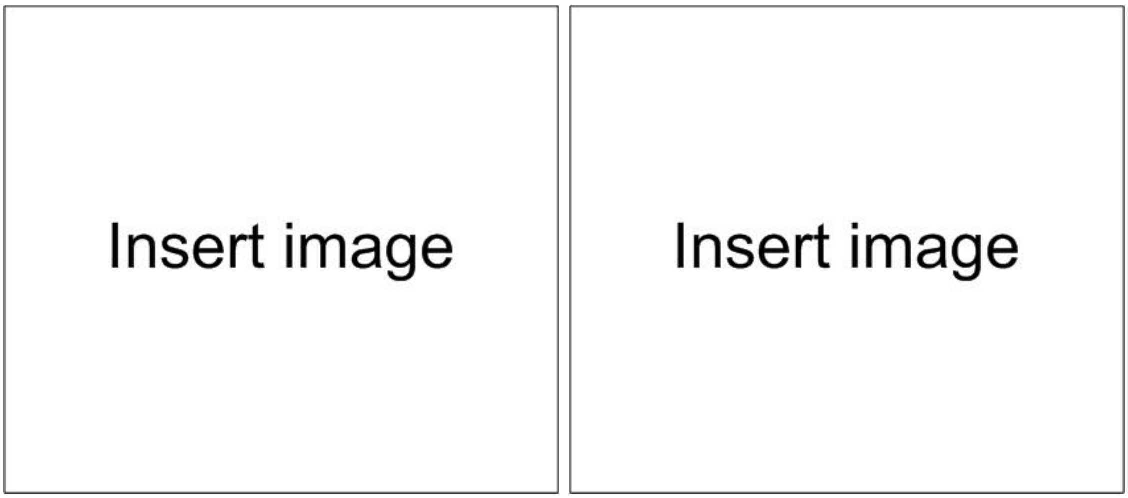


Figure 1.3 – *This is a figure caption*

An alternative is to use the "subfigure" command inside the "figure" environment. You need the

```
\usepackage[center]{subfigure}
```

command in your preamble. With this command, the figures will be labelled a, b, c etc.



(a) Caption for subfigure 1 (b) Caption for subfigure 2

Figure 1.4 – *General caption*

1.2 Tables

This is an example of a table:

Table 1.1 – *This is a table caption*

Header 1	**Header 2**	**Header 3**
Some text	Some text	Some text
Some more text	Some more text	Some more text

You can also do a table with multi-line cells:

Table 1.2 – *This is a table caption*

Header 1	**Header 2**	**Header 3**
Some long text that does not fit in a single-line table cell	Some text	Some text
Some more text	Another very long text that does not fit in a single-line table cell	Some more text

1.3 Equations

You can do simple in-line equations by using the "$" symbols around the equation: $2+2=4$. Remember always to use a the math- or equation environment when using variables like $+$, $=$, x^2, f_2 etc.

To write a numbered equation on its own line, use the "equation" environment:

$$T(s) = \frac{G(s)H(s)}{1+G(s)H(s)} \tag{1.1}$$

You can also do multi-line equation by using the "split" - environment:

$$\begin{split} 2x + 4y &= 6 \\ 4y &= 6 - 2x \\ y &= 1.5 - 0.5x \end{split} \tag{1.2}$$

1.4 Citations, References and Acronyms

This is a citation[**CitationReference1**].

This is a citation referring to a specific page in the cited work[**CitationReference1**]. You can also do multiple citations[**CitationReference1**, **CitationReference2**].

This is a cross-reference to a figure/section/table/equation etc. in the latex document: see Figure 1.1.

Use acronyms consistently to provide an easy-reading text: The Unmanned Solar Powered Airship Concept Evaluation (U-SPACE) project rocks!

Chapter 2

Introduction

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 a wireless connection with a ground station or controller. This connection enables control over the airship, together with retrieval of housekeeping and scientific payload data.

The same concept of a SPA has attracted major interest in recent years [**website:ravenaerostar**, **website:gaya**, **poster:saba**, **report:colozza2004**]. Such an airship could be used for a wide variety of applications, ranging from passenger and cargo transport [**website:gaya**] over scientific research [**poster:saba**] to planetary exploration [**report:colozza2004**]. 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. **EXAMPLES OF STUDENT PROJECTS?** 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.

2.1 Hardware

Description of the hardware, including a block diagram

2.2 Software

Description of software, including operational modes

Chapter 3

Design Requirements

some text...

3.1 Functional Requirements

What function(s) does the system have to fulfill?

- A requirement
- Another requirement
- Etc...

3.2 Technical Requirements

What technical requirements constrain the system design? - e.g. mass, power, strength, stability etc.

- A requirement
- Another requirement
- Etc...

3.3 Fault Tolerance Design and Safety Concept

N/A, but comment on it. Refer to MGSE for safety concept

3.4 Materials

Briefly comment on it

Chapter 4

Mechanical Structure and Envelope

General introduction to the subsystem...

4.1 Functional and Technical Requirements

Based on PDR...

4.2 Mechanical and Structural Design

As it was included in the PDR, the initial design of the U-SPACE included the development of a blimp (envelope) that would then accommodate the solar panels (power system), the cargo bay and the propelling system.

An initial view of this project is presented in Fig. 4.1.

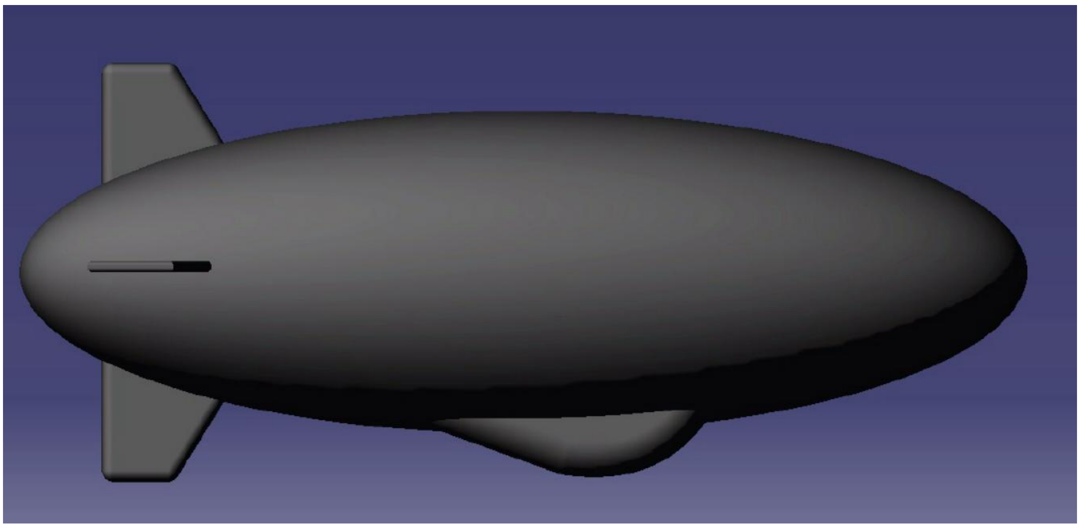


Figure 4.1 – *Initial 3D sketch of the Airship*

As it is possible to see, this simplified view of the mechanical challenge, included the total development of the airship. The idea would be to include the solar panels on the top mounted on a wired mesh and the cargo bay attached in the bottom together with the propelling system.
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), Fig. 4.2. This blimp has the capacity to lift a payload of about 2.5 Kg, it has a length of approximately 5 m and a diameter (in the center) of about 1.9 m.

Figure 4.2 – *TIF - 250 Blimp*

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

4.2.1 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 would had 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.

4.2.2 Cargo Bay

The cargo bay is intended to accommodate both the payload and the electronics required to the purpose of the project. The main challenge in the construction of this cargo bay is the weight, it has to be lightweight but at the same time rigid enough to resist to some stress during the normal operation of the airship. To achieve this, balsa wood reinforced with carbon fibres was used, the box should be rigid enough to resist to the external forces, but lightweight enough to able a total maximum weight of all the structures of less than 1 Kg. Figures of the expected final cargo bay and of the current construction status are presented in Fig.4.3 and 4.4, respectively.

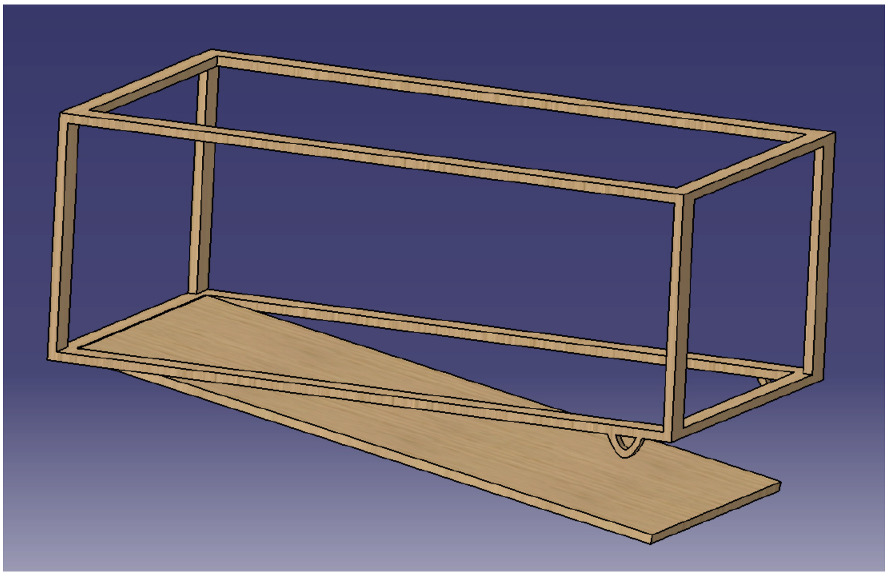


Figure 4.3 – *Cargo Bay 3D sketch*

4.2.3 Power System

The biggest challenge of this project is to accommodate the power system having into account the maximum lift weight and also the power requirements that consequently influence the solar panels 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 would serve as a support to the solar panels, attached

to the wires with carbon fibre, and then this mesh would be consequently connected to blimp making use of 3 bands that would round the blimp distributing the weight along the envelope. This bands would be made of fibre glass reinforced rubber tape.
An idea of how the final product should look is presented in Fig. 4.5.

4.2.4 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 would be attached in 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 Fig.4.6.

4.3 Future Developments

All the previously explained designs have to be built and tested. Conclusions have to be taken and inputs from the other systems have to be taken in consideration. Only after a careful building of the different structures to accommodate all the required systems, it will be possible to check if the requirement of the maximum lift weight - the most constrained one - is achieved. For now, the 3D designs, the intended to use 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 to the construction of the wiring mesh and consequent attachment of the solar panels.

• •

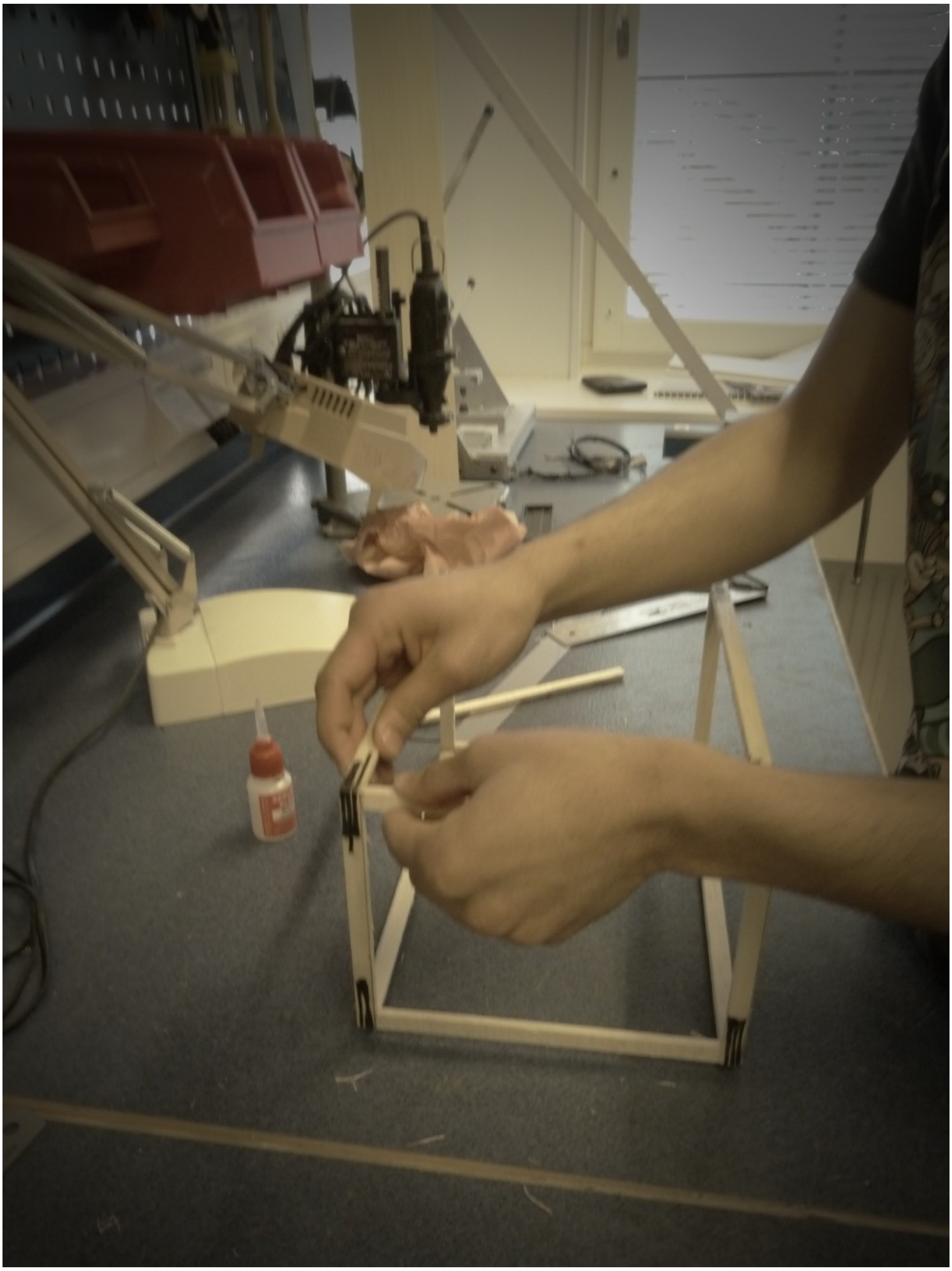


Figure 4.4 – *Initial phase construction of the cargo bay*

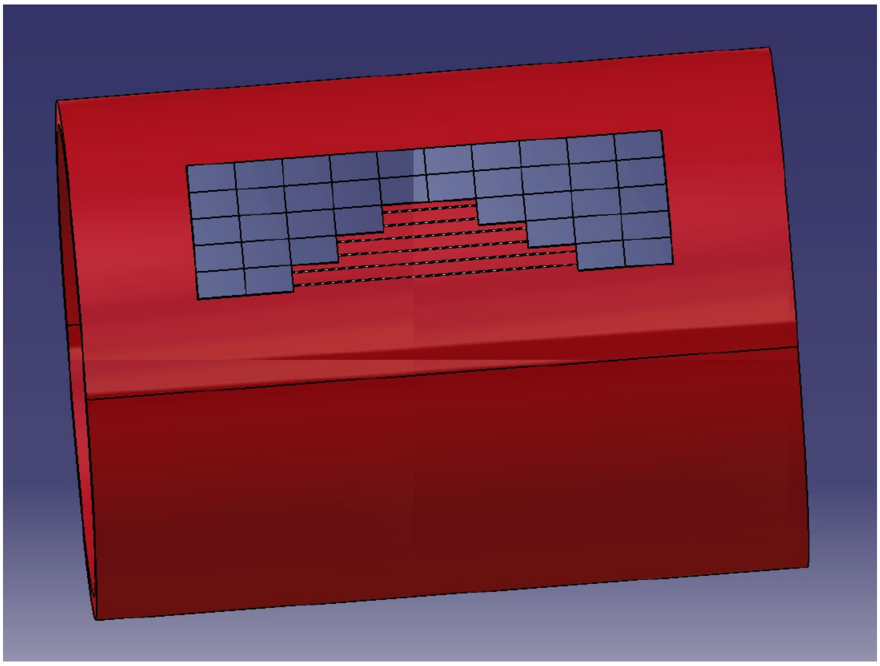


Figure 4.5 – *Integration of the power system - 3D sketch*

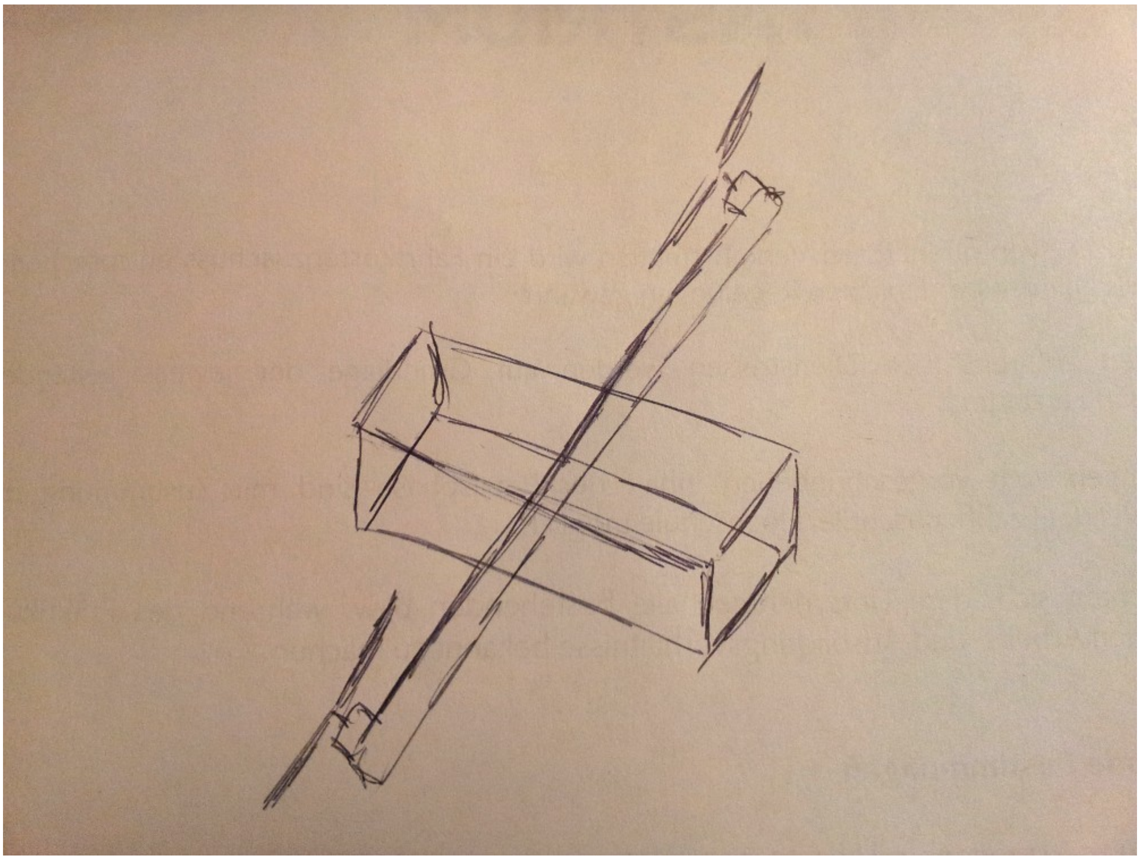


Figure 4.6 – *Hand sketch of the integration of the propelling system*

Chapter 5

Electrical Power System

General introduction to the subsystem...

5.1 Functional and Technical Requirements

Based on the PDR...

5.2 Power Distribution Block Diagram and Redundancy

Block diagram of the different power consumers...

5.3 Electrical Circuits

Explanation of all different circuits involved in the EPS subsystem...

Chapter 6

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 2.4GHz.

6.1 Functional and Technical Requirements

Below are listed the primary functional requirements for the MCC:

6.1.1 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

6.1.2 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 mot`http://www.rcflight.se/`ors 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 $27.6 \times 11mm$. 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.

6.1.3 Expected Performance

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

Figure 6.1 – *Motors purchased from http://www.rcflight.se*

6.2 Design of the System

The functioning of the MCC subsystem is shown in the Figure 6.2. 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.

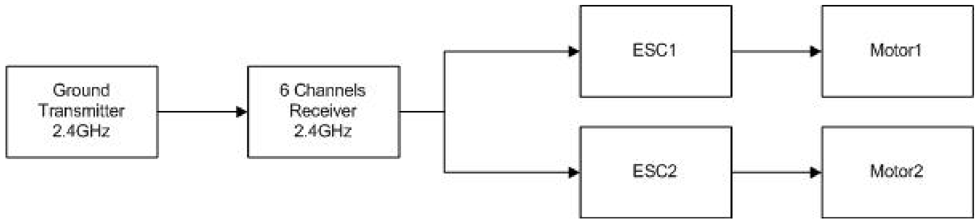


Figure 6.2 – *Block Diagram of the MCC Subsystem*

6.2.1 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 6.1 – *Trade off analysis*

It is clear from the Table 6.1, 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 primamry 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.

6.2.2 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.

6.2.3 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.

6.2.4 Telemetry and Telecommands

If time permits, it would be desirable to have a microprocessor for telecommanding and telemetry which is listed in Table 6.2

Telemetry	Data rate/frequency	Data size
Battery voltage	Every 30 sec	1 byte
Solar array temperature	Every 30 sec	1 byte
Solar array voltage	Every 1 sec(MPPT Performance)	2 bytes
Solar array temperature	Every 1 sec (MPPT Performance	2 bytes

Table 6.2 – *Telemetry*

Chapter 7

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.

7.1 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.

7.2 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 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 [**LSM303:datasheet**] combined magnetometer and accelerometer and the ITG-3200 triple-axis gyroscope [**ITG-3200:datasheet**] 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.

7.3 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 7.5. 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.

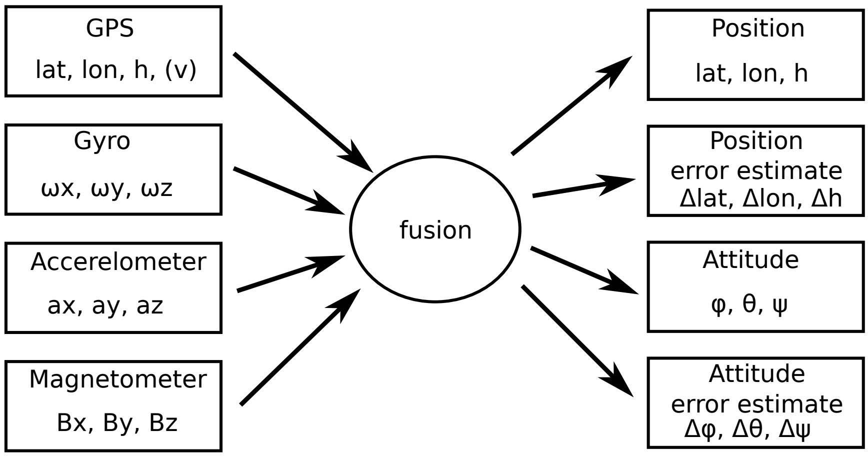


Figure 7.1 – *Attitude Determination System overview*

7.4 Image processing

7.5 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 7.1):

- 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.

7.6 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.

[...]

Chapter 8

Thermal Interfaces, Pyrotechnics and Electromagnetic Compatibility

N/A but just comment on all of it briefly...

8.1 Thermal Interfaces

Some comments... E.g. why not applicable?

8.2 Pyrotechnics Interface

Some comments... Why not applicable?

8.3 Electromagnetic Compatibility

Some comments, e.g. grounding...

Chapter 9

Test and Verification of Design

9.1 Design Verification Plan

9.1.1 Objectives and Responsibilities

Why and who?

9.1.2 Verification By Analysis

N/A, but comment on it briefly...

9.1.3 Verification By Test

Write about test procedures...

9.1.4 Verification Control System

Not sure if this is applicable, but if yes, then the answer should be github I guess...

9.2 Subsystem Test Matrices

Different tests presented as a matrix/table: rows are test modules, columns are possible testing techniques. Maybe one per subsystem? Also limited life time elements could be included here...

Chapter 10

Ground Support Equipment

10.1 Electrical Ground Support Equipment (EGSE)

Based on PDR...

10.1.1 Concept

10.1.2 Hardware Description

Instrument, user and network interface...

10.1.3 Software Description

10.1.4 Compliance

10.2 Mechanical Ground Support Equipment (MGSE)

Based on PDR...

Chapter 11

Project Management

11.1 Organisation and Responsibilities

11.1.1 Key Personnel and Responsibilities

11.1.2 Functional Organigram

11.1.3 Support Facilities

Esrange, IRF, etc.

11.1.4 Shipment

Might be useful to already give it some thought...

11.2 Relation With Support Facilities

11.2.1 Reporting and Monitoring

11.2.2 Reviews

11.2.3 Component Ordering

11.3 Financing

11.4 Schedule and Milestones

Updated from PDR...

11.5 Configuration Control

How are design changes tracked and discussed?

11.6 Deliverables

11.6.1 Hardware and Software

11.6.2 Documentation

11.6.3 Deliverable Items and Build Standard

Not absolutely clear what this means... Morten?

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Appendix A

Some Appendix

some text...

Appendix B

Another Appendix

some text...