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Laser Swarm

Baseline Report

Design Synthesis Exercise

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Abstract

In February 2010 the ICESat mission ended after 7 years of for measuring ice sheet mass balance, cloud and aerosol heights, as well as land topography and vegetation characteristics, using a space based Light Detection And Ranging (LiDAR). ICESat followed only one of the possible approaches for LiDAR, namely the use of a high energy laser and a large receiver telescope, the other approach is using a high frequency low energy laser and a single photon detector. The advantage of the latter approach is that it has a much lower mass, but it is unsure if even a single photon per pulse reaches the receiver. One possible solution could be the use a swarm of satellites around the emitter, each equipped with a single photon detector, however the technical feasibility of this concept has not yet been proved.

This baseline report provides an overview of the initial look into this concept. This document contains the requirements analysis, functional breakdowns, risk assessments and initial design options. Preliminary business assessment is also conducted at this stage. It provides the basis for the trade of made later in the project to find the most feasible system making use of this concept.

Contents

List of Acronyms

ADCS Attitude Determination and Control Subsystem

EOL End-of-life

FBS Functional Breakdown Structure

FFD Functional Flow Diagram

GLAS Geoscience Laser Altimeter System

LiDAR Light Detection And Ranging

MNS Mission Need Statement

RAMS Reliability, Availability, Maintainability and Safety

Chapter 1

Introduction

In February 2010 the ICESat mission ended after 7 years of for measuring ice sheet mass balance, cloud and aerosol heights, as well as land topography and vegetation characteristics. To do all this, ICESat had only one instrument on board: a space based LiDAR, allowing an unprecedented 3D view of the Earth's surface and atmosphere. However the laser lifetimes were severely limited because of a manufacturing error in one of the laser components. But ICESat followed only one of the possible approaches for LiDAR, namely the use of a high energy laser and a large receiver telescope, the other approach is using a high frequency low energy laser and a single photon detector. The advantage of the latter approach is that it has a much lower mass, but it is unsure if even a single photon per pulse reaches the receiver. One possible solution could be the use a swarm of satellites around the emitter, each equipped with a single photon detector, however the technical feasibility of this concept has not yet been proved.

This is the baseline report on the technical feasibility of this approach to achieve one or more applications of ICESat, it will mainly go into depth on the requirements, technical risks and define the initial design options. This way it will be the basis for the technical trade off to be made,which specifically requires the in depth understanding of the subjects treated in this report. Although decisions regarding the requirements can already be made, all decisions between technical concepts have to be postponed until the mid term report.

In chapter 2 the functions and requirements are described, in chapter 3 budget breakdowns in several areas are treated, in chapter 4 the technical risks are investigated, in chapter 5 the different design options are presented, in chapter 6 the sustainable strategy development is discussed, in chapter 7 the return on investment and operational profit are discussed and finally in chapter 8 the Reliability, Availability, Maintainability and Safety (RAMS) are studied.

Chapter 2

Functions and Requirements

2.1 Functional Flow Diagram

The Functional Flow Diagram (FFD) shows the functions the system needs to perform during its mission life. The schematic representation can be found in figure 2.1 on page 5.

The first thing that needs to happen, after being build, is that the satellites are put into their orbits and pointed towards Earth. After that the measurements can start; the emitter sends down laser pulses and notifies the receivers signals are sent. The receivers can adjust their attitude and then pick up reflected photons, turn them into an electric signal and inform the computer, which puts the data in a buffer. The data of the receivers can be either directly to a ground station or first send to the main satellite (the emitter) and then to the ground. The data on the ground can be split up made into data packages, which can be distributed to research institutes and other interested parties. With those datasets the terrain model can be produced. At the End-of-life (EOL) of the mission the satellites are decommissioned to make room for other satellites.

2.2 Functional Breakdown Structure

The Functional Breakdown Structure (FBS) shows the functions the system needs to perform broken up in subtasks from other functions. The schematic representation can be found in figure 2.2 on page 7.

The main function for the system is to be able to produce a terrain model, which is the reason to make the measurements. To be able to produce the terrain model the measurements need to be made, the data needs to be transferred to the ground and the data needs to be analysed. Because the mission needs to be sustainable the satellites are decommissioned at the end of their life, so they will not pose a threat to other satellites in the same orbit. The making of measurements depends on laser pulses to be send, returning photons to be detected and for the emitter and receivers to be in orbit with the instruments calibrated. For the data to be transmitted to Earth the antenna needs to be pointed to the ground station and the data package has to be transmitted. Data analysis depends on the data to be received on the ground and the distribution between the research institutes.

To have the satellite send out laser pulses the satellite needs to point down (nadir-pointing) and the emitter sends the pulses. The receiving of photons depends on the receiver being pointed at the ground target and

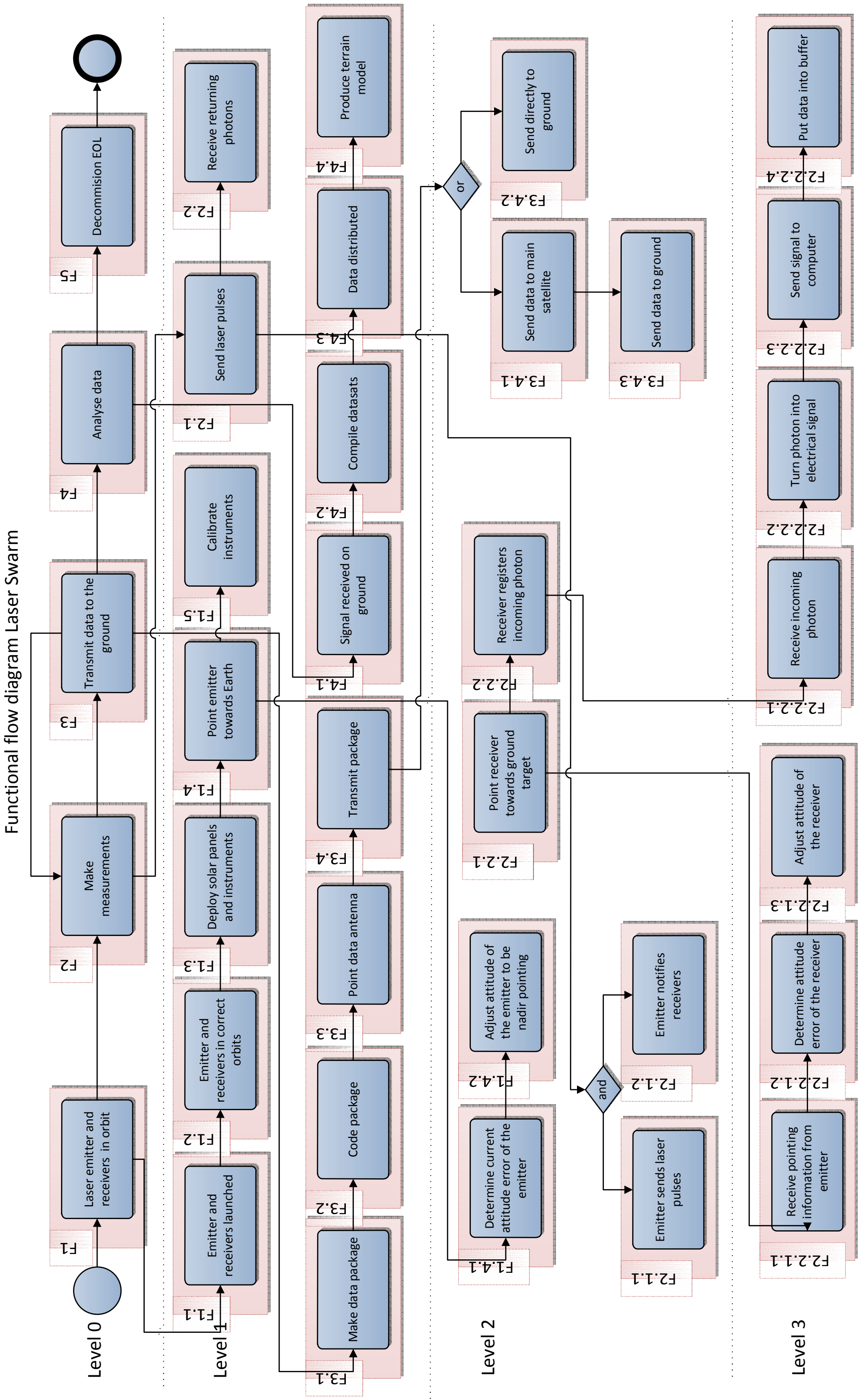

Figure 2.1: Functional flow diagram of the Laser Swarm mission

the receiver is able to register incoming photons. For the data package to be transmitted, data is put into a buffer, a data package is made, the package is code and either the receiver sends the data to the ground directly or to the main satellite, which in turn forwards it to Earth. When the emitter and receiver are in orbit, the emitter and receivers have been launched and they need to be on the correct orbits. It is important to have the solar panels and instruments to be deployed before they can be calibrated.

Determining the attitude error of the emitter and adjusting the attitude accordingly are required to point the emitter towards Earth. When an incoming photon is received, it is transformed into an electrical signal and the signal is sent to the on-board computer the photon is registered. For the receiver to be pointed at the ground target, the emitter needs to notify the receiver it has sent pulses, the receiver needs to receive the message, the attitude error of the receiver needs to be determined and the attitude should be adapted accordingly.

2.3 Requirement Discovery Tree

The requirement discovery process begins with the restatement of the mission need statement. From there, the top level requirements and their derivatives can be analysed.

2.3.1 Mission Need Statement

Demonstrate that a satellite constellation, consisting of a single emitter and several receivers, will perform superior (in terms of cost and lifetime) to existing spaceborne laser altimetry systems.

2.3.2 Requirement Discovery

From the Mission Need Statement (MNS) in section 2.3.1, it possible to deduce the top level requirements of this project. They are as follows:

- Cost budget below existing spaceborne laser altimetry systems.
- Lifetime above existing spaceborne laser altimetry systems.

Furthermore, several more requirements were provided by the principle tutor:

- Mass budget below or equal to existing spaceborne laser altimetry systems.
- No scanner may be used.

The last requirement is mainly considered as a pure constraint. The constellation should be designed as a collection of pointing devices.

The other three top requirements have been put in respective Requirement Discovery Trees (RDT) in appendix A. The following sections contain a brief discussion of each of these breakdowns.

Cost Budget Requirement

The cost budget requirement is mainly based on the analysis of the costs of current laser altimetry systems. As a reference point, the estimated budget of the ICESat system was taken: around $200m[1]. From hereon, the cost requirement was broken down into three main parts: payload, bus and *wraps*.

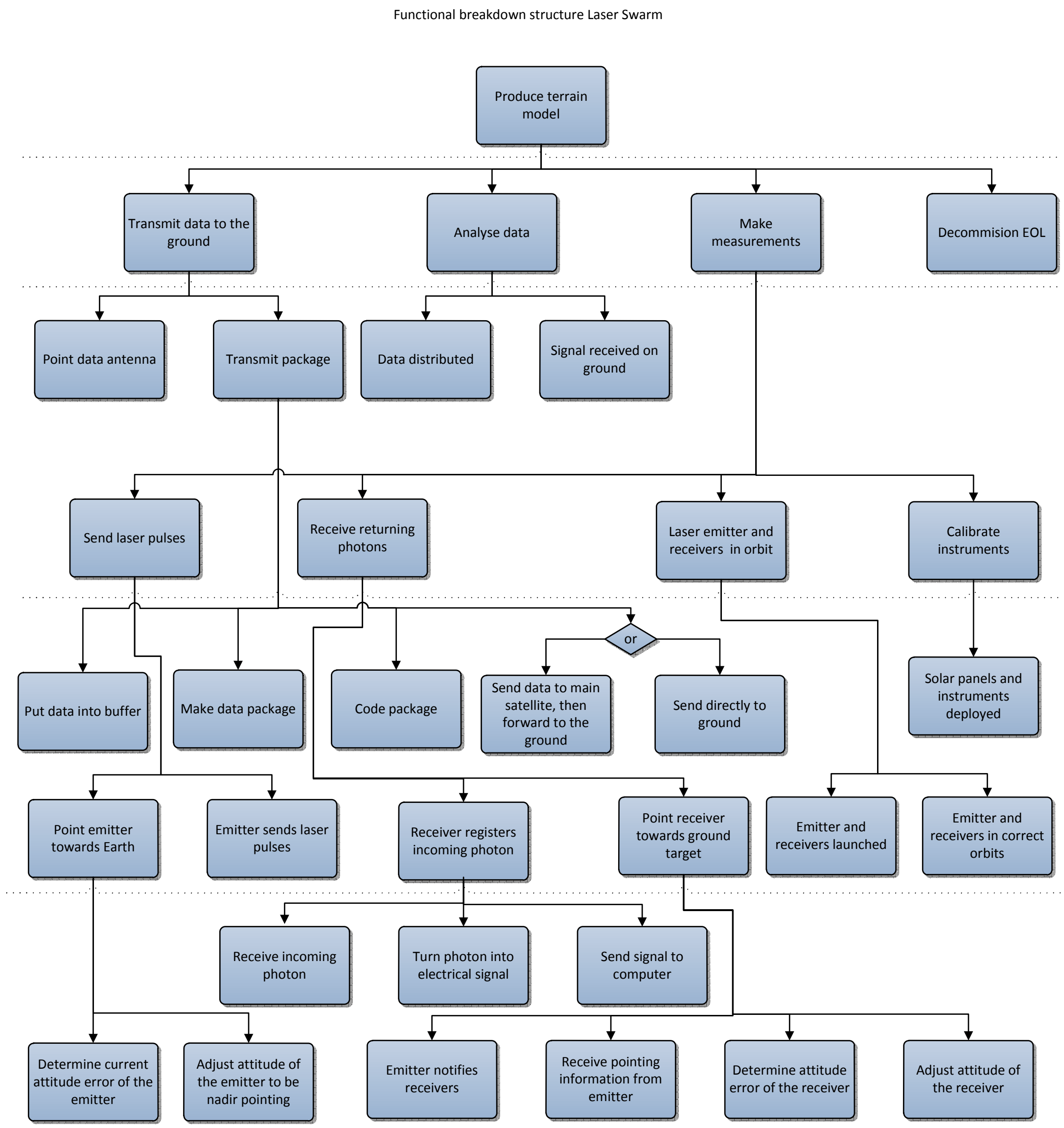

Figure 2.2: Functional breakdown structure of the Laser Swarm mission

The payload defines the design requirements for the emitter and the receivers. These are then further broken down into smaller considerations.

The bus requirements are those imposed on different spacecraft subsystems, excluding the payload. Only those systems that fall under the scope of the feasibility study are examined. Spacecraft structures and thermal control are taken to have a standard budget percentage and are not elaborated. Spacecraft power, data handling and Attitude Determination and Control Subsystem (ADCS) are considered to be critical design parts thus, have their requirements listed to maximum detail.

The final section - *wraps*, contains non-physical factors, such as system engineering, management and product testing. Since *wraps* typically account for close to 30% of the total budget[2], it was imperative that these systems would be accounted, yet their design was assumed to be similar to the design of current laser altimetry systems.

Mass Budget Requirement

The mass budget is also a very important requirement. In order to keep total mass to the minimum (to ensure a cheap and unified launch), all critical subsystems and the payload have to be examined. In this sense, the requirement discovery tree for the mass budget looks very similar to that of the cost requirement. This is because all these design choices effect both factors. Some preliminary dry mass percentages (based on statistical data[2]) have been added to the tree to illustrate a primitive order of importance.

Lifetime Requirement

The lifetime requirement is quite crucial. From the experience of ICESat it is apparent that payload quality (especially that of the laser) plays a pivotal role. The ICESat mission provided the satellite with three lasers in the Geoscience Laser Altimeter System (GLAS), first of which stopped emitting pulses on operating day 37.

Chapter 3

Budgets

Chapter 4

Technical Risk Assessment

Chapter 5

Design Options

Chapter 6

Approach with respect to sustainable development

Chapter 7

Return on Investment and Operational Profit

Chapter 8

R.A.M.S.

In this chapter the approach to the RAMS characteristics of the satellite system are described. In the upcoming sections all aspects are threaded separately.

8.1 Reliability

Compared to conventional laser altimetry missions, a swarm of receivers is used in this system. Spreading the receivers over a number of satellites reduces the risk of the mission failing. If one receiver satellite fails there will still be others to perform the task of detecting photons. Using a low-power laser emitter extends the lifetime of the mission compared to missions using a higher power laser, since low-power lasers generally wear out slower. Figure 8.1 on page 16 gives a overview of subsystem contributions to satellite failures after different time span from a non-parametric analysis. More detail reliability analysis can be found in chapter risk assessment.

8.2 Availability

The system is designed functional all the time to cover the entire Earth. To safe power it is also possible of switch off the laser to only make measurements in a designated area. Since the system use a swarm of receivers the system can still make measurements if some of the receivers in pointed in the wrong direction.

8.3 Maintainability

Maintainability is defined as the ability of our operating system specific item to be maintained. In our case, as with most other satellite missions, it is not possible to do regular on-board maintenance to the satellites themselves. The main focus in maintenance is on the ground segment and can be divided in two parts: preventive maintenance and corrective maintenance. They are considering separately as follows:

1. Preventive maintenance. During the regular system operation time, there are periodic maintenance and condition dependent maintenance. System software or simulator servicing maintenance of ground station is mandatory and data link rate needs to be adjusted in some cases. On the other hand,

conditional maintenance is set to do some specific inspections to prevent something going wrong in the future.

2. Corrective maintenance. This is mainly carried out after something goes wrong. For instance, if one of the photon receiver is not functional, the system can relocate the rest of the receivers to decrease the functional influence mostly. But if the laser emitter is broken, it is no way to obtain the maintenance. Corrective maintenance is also used during analyzing measurements data to obtain better resolution or accuracy.

Since the mission consists of a swarm of satellites it will be possible to add more satellites to the swarm, for example to upgrade the mission or extend the mission life.

8.4 Safety

The system safety is mainly considered during launch and decommissioning. The safety risks during launch are mainly covered by choosing a reliable launcher. For decommission it is important to choose a decent orbit in such a way that it ensures the satellite to burn up in the atmosphere entirely. Most of the time the satellite is on its orbit in space. The orbits of the satellites need to be designed in such a way that they will not intervene with the orbits of other satellites, even when the satellite fails.

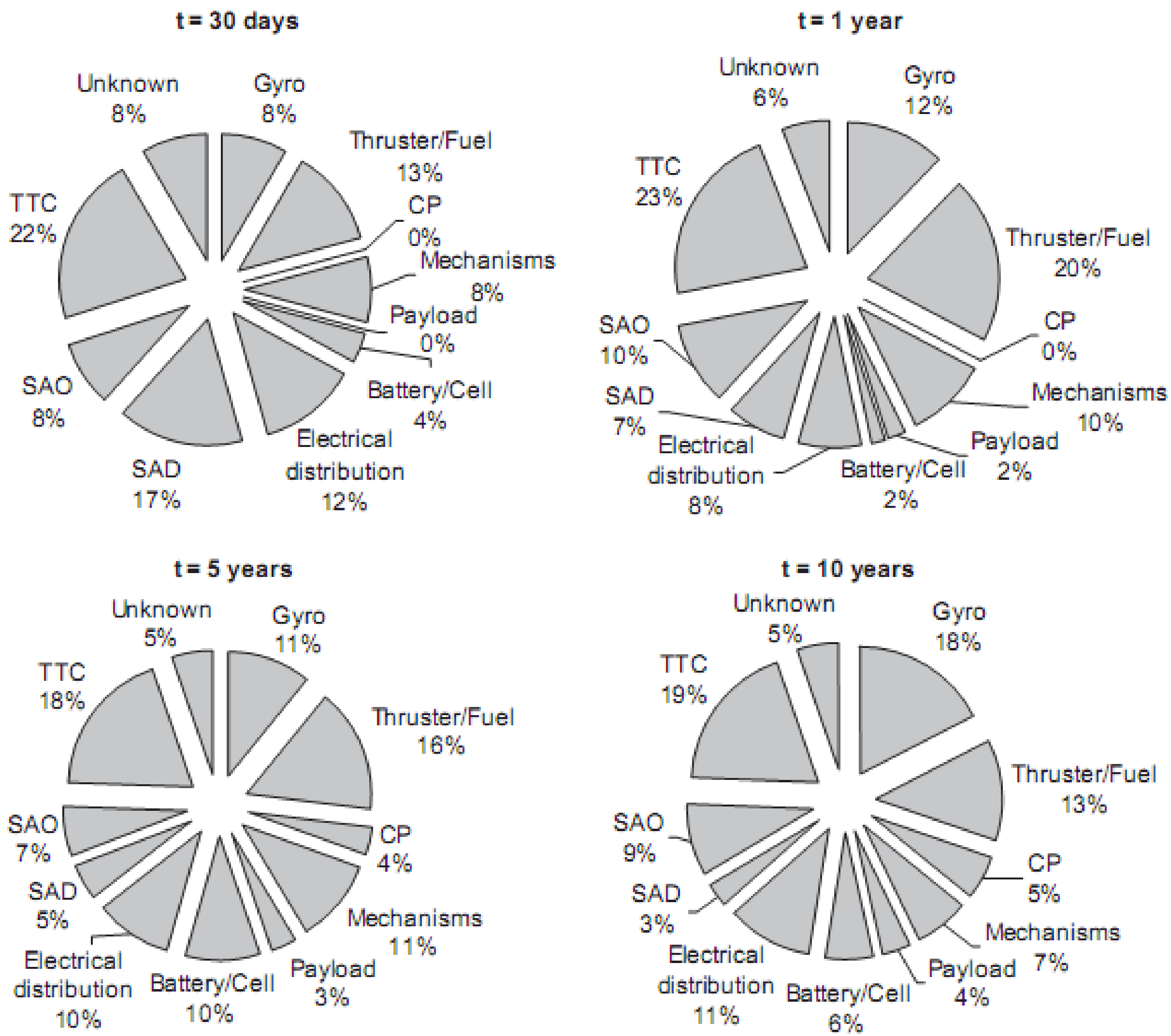

Figure 8.1: Subsystem contributions to satellite failures after 30 days, 1 year, 5 years, and 10 years in-orbit.

Bibliography

[1] Douglas Isbell. Icesat press release c98-a.

[2] Wiley J. Larson & James R. Wertz, editor. *Space Mission Analysis And Design.* Microcosm Press and Springer, El Segundo, CA (Microcosm Press) & New York, NY (Springer), 3 edition, 2006.

Appendix A

Requirement Discovery Trees