Delft University of Technology

Laser Swarm

Mid Term Review

Design Synthesis Exercise

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Abstract

In February 2010 the ICESat mission ended after 7 years of 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) system. ICESat used 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 uncertain if even a single photon per pulse reaches the receiver. One possible solution could be to 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 proven.

The 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. A preliminary business assessment is also conducted at this stage. It provides the basis for the trade-off made later in the project to find the most feasible system, which incorporates this concept.

Contents

List of Acronyms

ADCS Attitude Determination and Control Subsystem

CMG Control Moment Gyro

EPS Electrical Power System

GLAS Geoscience Laser Altimeter System

LEO Low Earth Orbit

LiDAR Light Detection And Ranging

RAMS Reliability, Availability, Maintainability and Safety

Chapter 1

Introduction

In February 2010 the ICESat mission ended after 7 years of 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 system (Geoscience Laser Altimeter System (GLAS)), allowing for an unprecedented 3D view of the Earth's surface and atmosphere. The laser lifetimes, however, were severely limited because of manufacturing errors in one of the laser components.

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 uncertain if even a single photon per pulse reaches the receiver. One possible solution could be the use of 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 proven.

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. 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.

Chapter **??** describes the functions and requirements of the system as a whole, whereas Chapter **??** shows the multiple budget breakdowns and resource allocation. In Chapter **??** the technical risks are investigated. Chapter **??** illustrates the different design options. Since sustainable engineering is an important factor, Chapter **??** is devoted to this subject. In Chapter **??** the return on investment and operational profit are discussed and finally in Chapter **??** the Reliability, Availability, Maintainability and Safety (RAMS) are studied.

Chapter 2

Technical Design Development

In this chapter an update is given on the Technical Design Development as given in the Project Plan. All charts and documents have been updated.

2.1 Project Approach Description

2.1.1 Group Procedures

The DSE project is approached by first establishing specific roles for the group members, so that every group member is assigned a clearly defined managerial and technical function. After this the group operational procedures are defined. They are as follows:

1. The Chairman will lead a 'scrum' meeting every morning upon arrival of all members to establish what everyone has done the day before and what they will be doing the day of the meeting. This is done in order to keep all members up-to-date with all aspects of the project. The meeting concludes with updates on any external communications (with organizations and teaching staff) as well as any other points relevant at that time.
2. When done, groups responsible for certain design tasks will present their results to the rest of the team.
3. The team meets with tutor and coaches at least weekly.
4. Everyone is present at The Fellowship between 09:00 and 17:00 every workday, except for a 45 minute lunch break.
5. Upon completion of a deliverable, a meeting is conducted to establish a plan for the next deliverable.

2.1.2 Reporting

The reporting is done in LaTeX. There is a main report file which contains the layout of the report and the references to other files that contain the chapters, sections, figures, tables and other documents required for the report. When the file is compiled and printed it will show the entire report.

This has the advantage that work can be easily divided among group members, and any change made to a file will not influence the rest of the report. The file sharing is performed using Subversion (SVN). SVN not only allows file sharing, but it automatically assigns versions to a document and keeps track of changes. The repository is hosted with Google^{TM}Code.

2.1.3 Project Outline

The official start of the DSE project is the establishment of the Mission Need Statement. At this point all members should be aware of the main goal of the assignment.

The design process is started by defining the tasks in the project plan, then finding the requirements and functions. From the requirements, a set of design options will be created for the Mid Term Review (MTR). In the MTR a trade-off will be made based on an extensive functional and risk assessment. After the MTR, work on the detailed design can begin. At this stage all subsystems will be given a careful consideration in terms of cost, mass and power budgets. Final decisions on detailed parameters and variables will be made. Leading up to the Final Review (FR), the feasibility study can be concluded.

Parallel to the design phase, the simulator software will be developed by a team of 3 to 4 people, depending on workload and time available. This software should be able to perform calculations accurate enough to aid the trade-off scheduled before the MTR.

Chapter 3

Preliminary Pruning of the Design Option Tree

In this chapter the Design Option Tree is pruned. This means that all options that can be dismissed offhand are removed so as to end up with a table of only serious design options. In section 3.1 the Attitude Determination and Control Subsystem (ADCS) is pruned, whereas orbit options are scrapped in section 3.2.

3.1 Attitude Determination and Control Subsystem

The gravity-gradient stabilisation and passive magnetic options are eliminated because they provide insufficient accuracy and do not allow pointing to a any target other than the mass or magnetic centre of the Earth. The spin stabilisation option is pruned because the satellite needs to be able to make measurements continuously. Double gimbal Control Moment Gyros (CMGs) are also not a viable option, because they are too complex and heavy compared to the other systems. For the attitude determination the initial measurements and magnetometers options are eliminated because of their low accuracy over time. The pruned design option tree can be found in figure 3.1 on page 7.

3.2 Orbit Characteristics

The orbits are determined depending on the characteristics of the payload. Because the payload uses a low power laser this means that the orbits will have to be Low Earth Orbit (LEO) in order for the laser to get any photons to the receivers. The resulting design option tree can be found in figure 3.2, page 8. Further pruning is not possible without a detailed analysis of the remaining options — which will take place in the tradeoff.

3.3 Electrical Power System

In the next section the design option tree for the Electrical Power System (EPS) will be pruned. The design option trees for the power source, storage, distribution and regulation and control will be dealt with individually in sections 3.3.1, 3.3.2 and 3.3.3 respectively.

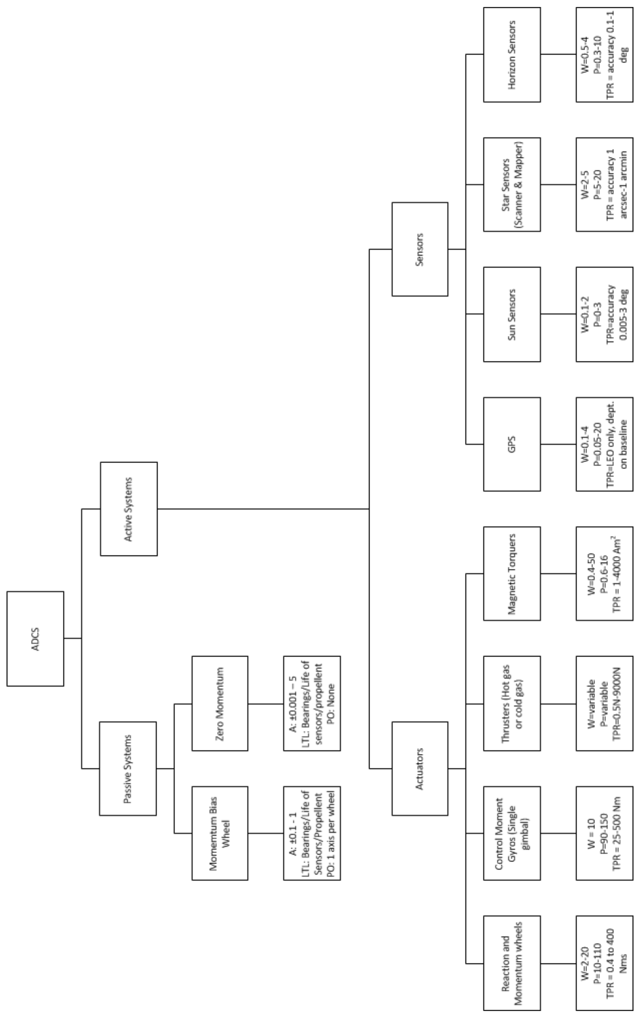

Figure 3.1: Pruned design option tree for the ADCS

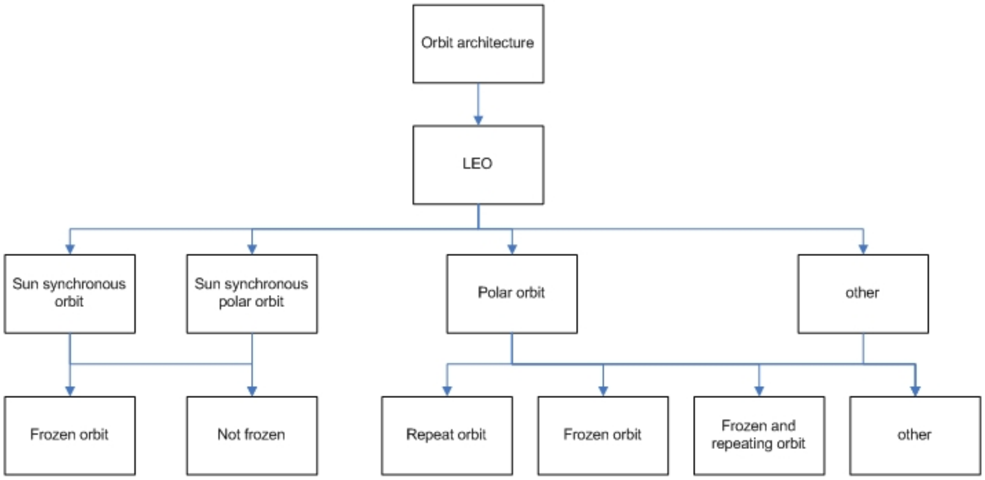

Figure 3.2: Pruned design option tree for the orbit characteristics

3.3.1 Power Source

Fuel cells have a high specific energy density but were not taken into account as a feasible power source because the amount of reactant they would have to bring for long term mission is too large for microsatellites. Primary batteries were equally unfeasible because of their limited lifetime, which is in the order of minutes to months. Radio isotopes and nuclear fission reactors were discarded because of their high cost and low specific power, as were thermionic and thermoelectric conversion for static power sources. This leaves photovoltaics and concentrated solar radiation together with an engine in a thermodynamic power cycle.

3.3.2 Power Storage

The only obvious candidate for power storage was secondary batteries because, as mentioned before, the lifetime of primary batteries is too short. Of the most common secondary batteries, sodium-sulfur batteries are not an option for us because their operating temperature at 350 degrees Celsius is too high.

3.3.3 Power Distribution, Regulation and Control

For the power distribution, regulation and control there were no obvious non-candidates. Because the power distribution, regulation and control depend on the type of power source, which depends on the payload power requirements, pruning will be done later on after these subsystems have been chosen — this is done in the tradeoff.

Chapter 4

Sustainable Development Strategy

In this chapter a Sustainable Development Strategy is discussed in the order of production (section 4.1, page 9), operations (section 4.2, page 9) and end of life (section 4.3, page 10).

4.1 Production and Logistics

The design is aimed at a swarm of mostly identical satellites. This may allow for series production which is more efficient in terms of resources than a one-of large satellite with a lot of unique components. This also implies that the number of different spare parts could be reduced. Smaller satellites could also use smaller facilities for production and testing.

Transportation can be split up into two parts: transportation to the launch site and the launch from the surface to the final orbit in space. On both occasions the system can again profit from its small size. If the satellites are not launched all together, they can piggyback on another satellite's launcher.

Spreading the swarm, i.e. piggybacking using different launchers, has several advantages. First of all the emissions are lower than in case of a dedicated launcher. Also, if the first satellite fails before the launch of the rest of the swarm, the others can be repaired and thus less resources are wasted.

4.2 Operations

Once in orbit, the satellite's influence on the Earth is very limited. The only real concern is the debris it leaves behind during launch and deployment, which can be dangerous to other satellites orbiting the Earth. The deployment mechanism however, which is responsible for most of the debris, is not included in this technical feasibility study. Later studies developing the ideas from this feasibility study should keep an eye on it, since more satellites could mean more deployment mechanisms and hence more waste. One aspect that can be dealt with is the efficient use of resources. The swarm can be designed in such a way that if one of the satellites fails a replacement satellite can be sent, whilst any remaining satellites can be reused.

4.3 End of Life

Each satellite will be at the end of its life if it cannot perform its function anymore. It is important that after the mission is over all satellites are removed from their orbit and burn up in the atmosphere so that they do not pose any danger to other satellites. Final decommissioning of the swarm will be more complex than for a regular satellite, since every individual satellite has to be decommissioned separately.

Bibliography