Experience and Methodology gained from 4 years of Student Satellite Projects

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Experience and Methodology gained from 4 years of Student Satellite Projects

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***Abstract*— The AAU Cubesat student satellite project at Aalborg University was initiated in September 2001 and led to the launch of the satellite on the 30th of June 2003 with a "Rockot" rocket from Plesetsk in Russia. The satellite survived three months in orbit and based on the experiences gained the next student satellite project was commenced called AAUSAT II which is due for launch early 2006.**

This paper presents the experiences gained and lessons learned from the work with student satellite projects at Aalborg University as well as the methodology used to manage these projects. First an introduction to the concept of student satellite projects is given and the two student satellite projects are introduced. Then an introduction and description of the Problem Based Learning concept used at Aalborg University is given and advantages of applying it to these projects are discussed. The benefits of student satellite projects are also discussed. Finally the specific management methods for the two projects are described and lessons learned from each project as well as a set of recommendations for future projects are given.

I. Introduction

For four years since the summer of 2001 student satellite projects have been an integrated part of the education of students at Aalborg University (AAU). The projects have so far been focused mainly around three satellite projects: The AAU Cubesat which was the first cubesat built at AAU, The AAUSAT II which is the successor of AAU Cubesat and is due for launch in Q1 2006 and SSETI Express which is a microsatellite organised by the Education department of ESA. The first two satellites have been made entirely on an in-house framework at AAU using the cubesat-concept while the latter is a corporation between 12 universities around Europe [1]. This paper will focus on the two cubesats built in-house and the structuring of these projects.

It was the creation of the cubesat-concept which initiated the student satellite projects at AAU and it has been developed at Stanford University and California polytechnic institute led by professor Bob Twiggs [5]. This concept allows a satellite of dimensions 10x10x10cm and mass 1kg to be launched into low Earth Orbit under simple interface conditions at a total launch cost of about $40,000. These constraints simplify the trouble of launching a satellite into orbit considerablely and so far at least 50 universities around the world has adopted the idea.

A. The Constraints of Student Satellite Projects

At the beginning of the AAU Cubesat project a number of important constraints were identified and generalised mission success criteria was formulated in an incremental way:

1) Educating engineers with theoretical as well as practical experience in spacecraft design and construction.
2) Acquire signal from the satellite.
3) Acquire comprehensive housekeeping data for system evaluation.
4) Satellite and payload operations.

Thus it was defined that the most important aspect of a student satellite project is to educate the students participating in it which means that a project can still become a partial success even though no signal is ever received from the satellite. The formulation was done this way in order to keep focus on the fact that the project is there for the students and not vice versa.

The constraints that were identified were used to steer and structure the projects:

- Short project (<2 years)
- Designed, implemented and operated by students
- Low budget

It was identified that it was very important to keep the duration of the project very short. When the students start on the project they must be able to see the end is within the timeframe of their own studies and before the students can contribute technically to the project they need some years of prior studies in the basics of their field.

Another important aspect that was identified is to allow the work of designing and building the satellite to be done entirely by students. While it is not always desirable or possible to adhere to this it is nevertheless an important point corresponding with the first success criterion.

It is also important to keep the project at a low budget for several reasons: The most important is of course that only limited funds exist at most universities for such educational projects and it is easier to find small a amount of money than a large. This also justifies the way of formulating the success criteria as the financial investment is kept low enough to accept the possibility of a failure of the satellite.

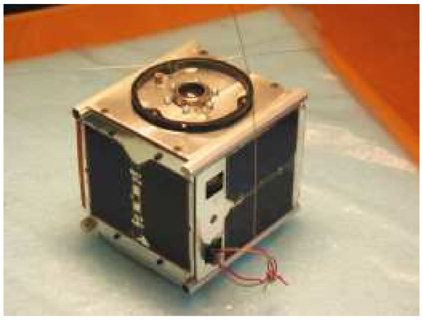

Fig. 1. The flight model of AAU Cubesat ready for launch.

In the following the two cubesats from Aalborg University are described first, whereafter an introduction to the Problem Based Learning method used at Aalborg University is given. Then a description of the motivational factors that support a student satellite project is given and finally the management methods used at the two cubesat projects are discussed.

II. AAU CUBESAT

AAU Cubesat was designed and built from the summer 2001 to the spring 2003 and included students from five different departments: Mechanical department, control department, electrical department, power electronics department and computer science. At the beginning of the project 70 students divided into 11 groups were involved with the different subsystems and this number was then reduced as the project progressed until the end where 5 students conducted the final integration and checkout.

The satellite consists of 5 electrical subsystems, the mechanical structure and the ground segment. The five electrical subsystems are: Power Supply Unit (PSU), On-Board Computer (OBC), Attitude Determination and Control system (ADCS), Communication system (COM) and the payload which was a camera. For a detailed review of the AAU Cubesat mission see [2].

The Power Supply Unit acquire power from 10 triple junction GaAs solarcells using a digital implemented Maximum Power Point Tracking algorithm. The estimated average power acquired of 1.4W is either stored in the batterypack consisting of 4 Lithium Ion polymer cells with a total capacity of 16Wh or consumed directly by the other subsystems. Furthermore the power supply unit is responsible for latch-up protection of the subsystems and all low level operation of the satellite like, bootmode of the OBC and transmission of safe-mode beacon.

The On-Board Computer feature a Siemens C161 10 Mhz microcontroller with 4 MB of RAM, 512 kB of PROM for initial software and 256 kB of Flash ROM for new software upload. The OBC is the master of the internal I2C bus to the PSU and ADCS, a combined I2C and DMA interface to the camera and a parallel interface to the COM.

To control the satellite in-orbit the ADCS system implement electromagnetic control using three magnetotorquers with two different possible modes: B-dot and inertial. The B-dot algorithm for detumbling the satellite and inertial mode is intended for pointing the camera at specific location on Earth using a constant gain controller. Attitude determination is done using a three axis magnetometer and sunsensors on all satellite sides which are fed into an extended kalman filter with additional input from a orbit propagation model (SGV4) and a magnetic field model.

The communication system consists of a 9600 baud MX909 packet modem and a commercial SX-450 radio with a 0.5W output into a crossed di-pole antenna which is deployed after orbit-insertion using a simple burn-mechanism. Modulation form is GMSK and the AX25 protocol is used for link management.

The camera is based on a Kodac CMOS sensor providing a resolution of 1280x1024 pixels in 24 bit color. The lens system for the camera is made from titanium and radiation hardened glass and provides a on-ground resolution of about 100x100 meter per pixel (see figure 2).

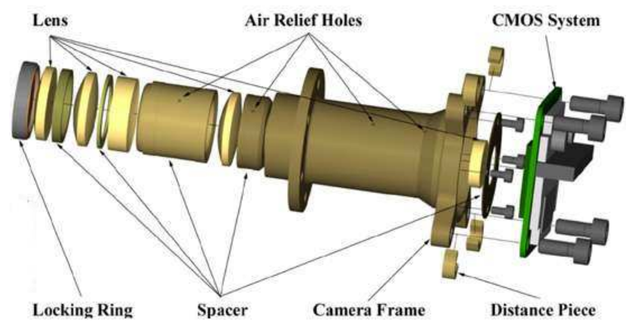

Fig. 2. The lens system of the AAU Cubesat camera.

The mechanical structure consists of a frame made from one solid block of aluminium on which carbonfibre side plates are mounted. The print circuit boards are mounted onto the frame on the inside.

A. After the Launch

The satellite was launched the 30th of June 2003 and due to communication problems it took 3 days before it could be reliably stated that beacons from AAU Cubesat were being received at the ground station. During the next three months the communication with the satellite was improved to the point where two-way communication could be established and housekeeping could be downloaded. Late September 2003 the satellite experienced a battery failure and it was declared inoperational with the first three of the success criteria fulfilled. The communication problems is estimated to originate from a failure in the antenna deployment mechanism which resulted in the two dipoles short-circuiting.

III. AAUSAT II

AAUSAT II is the successor of AAU Cubesat and the project was initiated September 2003. Based on the experiences gained with the former many mistakes will be avoided in the duration of the project. The actual satellite is redesigned from scratch – no subsystems are reused. Experience and knowledge transfer from AAU Cubesat to AAUSAT II students are carried out by old students of which some today are PhD students at AAU.

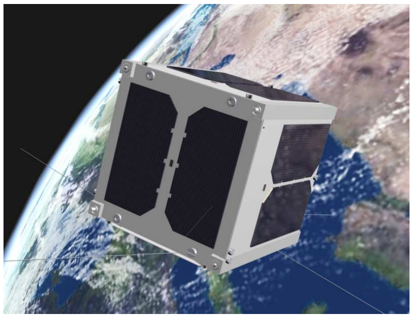

Fig. 3. A rendering of AAUSAT II in space.

AAUSAT II can be viewed as a new generation of AAU Cubesat and with use of newer technology: The OBC is a 32bit Atmel ARM7 running at 40 MHz with 2 MB of ram, 4 MB of Flash ROM and 4MB of Flash RAM taking up much less physical space than the old OBC. EPS has been completely redesigned to optimize efficiency. The ADCS uses the same sensors and actuators as on AAU Cubesat but furthermore it has been augmented with three small momentum wheels and three MEMS rate-gyros. To control the satellite with these momentum wheels is considered as a technological payload as this is a novel thing on such a small satellite. The structure has been made much easier to integrate and disintegrate and has been augmented with deployable solarpanels as a payload. Finally as the main payload the camera has been replaced with a miniature Gamma ray Burst Detector (GRBD) from the Danish Space Center which consists of a single CdZnTe detector crystal. The main objective of this novel detector is to test it in space before committing it to larger satellites. The detector can be used to detect gamma ray burst with a expected rate of 1 GRB/month. The onboard software continuously monitors the GRBD data flow for presence of GRBs and the data will be transmitted to ground with high (< 1 s) time resolution. For more detail of AAUSAT II see the webpage [4]. The finalization of the design and prototypes is ongoing primo 2005 and launch is scheduled for early 2006.

IV. Problem Based Learning

Before introducing how the projects have been and are managed and structured it is necessary to give an introduction to the educational method used at Aalborg University. The entire structure of the university is based around project organised problem based learning where the keyelement is that the students work in groups focused on a specific problem. Each half year semester the students must form groups of 3-6 students which gets a supervisor assigned and then carry out a major project besides following lectures. Both project and lectures support the theme of the semester which e.g. could be Real Time Systems etc. The project corresponds to about 600 hours per student which is equal to between 65% and 75% of the ECTS points of the semester.

The students carry out the projects all the way from problem formulation and analysis through the problem solving to the final result which is a 80-200 pages report and for the engineers a prototype of the system they have developed. The principle is shown in figure 4.

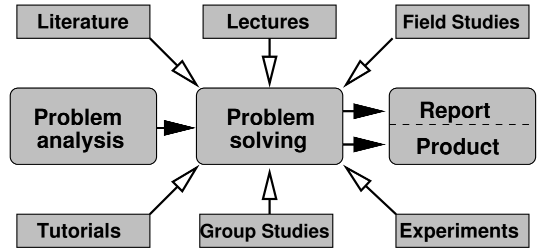

Fig. 4. The principle of the problem based project work at Aalborg University.

This organisation of the education system has proven to be very rewarding for the graduates who are highly praised by the industry and are very popular with the students themself. This is due to a number of facts: Students prefer real life engineering problems compared to hypothetical, academic problems. This leads to a highly profitable corporation with the local industry as many student projects are proposed by companies. The students urge themself on in the groups and almost always set much higher standards for their work than the university does and thus yielding very high quality results.

Aalborg University has a high reputation world wide for the PBL education model.

As a result of the problem based education the students acquires, besides a thorough theoretical insight, a large experience in applying the theoretical elements in practical engineering problems. The group based team work has taught the students how to professionally argument for and present their own proposals and how to be constructively critical to other proposals, i.e. not take solutions for granted. They have learned that it is not enough to believe you are right – you need to persuade your team members.

This structure of education is a very good basis for a student satellite project as it supports the division of the satellite into subsystems very well. For example for AAU Cubesat the following 8 subsystems were identified: Power Supply Unit, On-Board Computer, Attitude Determination and Control System, Communication system, Camera, Structure, Command and Data Handling System and Ground Station. All of these systems could all be fitted into a semester theme for a specialisation with everything from analysis through design to construction. This means that the work on the spacecraft fits well into the curriculum and the students automaticly get academic credit for their work which otherwise could be a problem. Also based on their experiences with combining practical and theoretical engineering work and their familiarity with team work the students are quite ready to take on a large project. Because while a student satellite project certainly contains a lot of technical challenges it most certainly also contains a lot of collaborative challenges and the students need to be able to handle that.

For a further elaboration of the Problem Based Learning method of AAU see [3].

V. Motivational Factors

There are a number of motivational factors involved in student satellite projects both seen from the point of view of students and the university but also from an educational point of view.

A. Motivation for the University

The overall motivation from the point of view of the university is to let engineering students from various areas of specialization and departments cooperate on a large scale project with a definite goal in mind. They learn to corporate not only within their own groups but also between groups and between completely different specializations, which is very similar to what they will experience when they go out into the industry. It is an excellent exercise in inter-disciplinary work and gives the students a good ballast for their future job positions as engineers in project-teams.

Another benefit is that the students are forced to make a product that is not just a prototype that only work most of the time, but instead they must mature their system into a completed product – just like in the industry. This means that they must create a system that can be qualified for space and can fit into the satellite and take into account problems like limited volume and limited power available. They must chose components that can withstand vacuum, the temperatures of space and the stress of the launch. Thus the students have already tried all phases of a product development and production when they graduate which makes them very attractive to the industry.

Also by involving the students in the actual management of the projects and the system-engineering work they acquire a, for students, unique experience in actual large-scale project management which is also very valuable to the industry.

B. Motivation for the Students

For the students a satellite project is a fantastic chance to make something that is not only used for a real life product but is actually launched into space. This is a huge motivational factor for the students as space is something many engineering students are very interested in.

A very important factor for both the university and the industry is the possibility of combining a student satellite project with actual research which creates benefits for both the satellite project and for the research project. The research can be involved in many ways either as part of the satellite platform like for example testing a novel ADCS control algorithm but also as a actual scientific payload like the Gamma Ray Burst Detector at AAUSAT II. The benefit for the professional researchers is that they can get their system into space in a very inexpensive way and get it flight tested in space before committing it to a large expensive satellite. The benefit for the student satellite project is that an actual scientific research mission adds professionalism to the project and makes it much easier to acquire funds.

However when introducing professionals into a student satellite project it is very important to remember the second requirement that was identified in the first section: *Designed and build by students*. It is important that the students and the professional researcher participate in the project on an equal basis – that the students are not simply used for doing the "dirty jobs".

VI. Managing the AAU Cubesat Project

When the AAU Cubesat project was initiated it was done by gathering into one room about 70 students from the different necessary specialisations who was interested in working with space technology. The project manager then outlined which subsystems were needed and what the expected functionality and responsibility of each subsystem were and then he announced that it was up to the students to find out who would do what and how and then he left the room. The students then spend the rest of the day dividing the responsibilities between them and discussing how to run the project. This story is very symptomatic for how the management of the AAU Cubesat project was carried out. It was from the start the intension that as much as possible should be left up to the students in a kind of controlled Laissez-faire management style. The management took care of finding funds, negotiating launch and dealing with legal issues while the students were responsible for the day to day management.

A project structure containing three bodies was defined: A steering committee, a supervisor group and the various project groups.

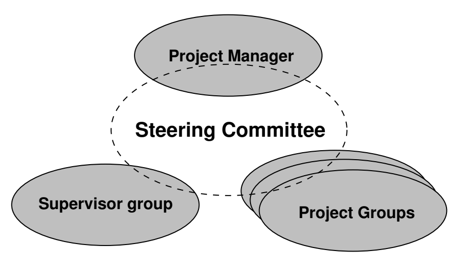

Fig. 5. The three body organization of the AAU Cubesat project.

The supervisor group consisted of the supervisors of the different project groups and the responsibility of this group was to monitor that the technical standard required for the project were maintained. The steering committee was the actual management group of the project with weekly meetings and it was run by the students with representative from each project group and the professor acting as project manager. Members of the supervisor group was represented at the meetings when appropriate for the particular discussion. The committee had the following objectives to oversee at the meetings:

- Define mission and payload.
- Discuss and determine interface specifications
- Ensure that loose threads were picked up

This structure worked quite well throughout the project but a number of problems presented themself as the project progressed. It soon became apparent that the supervisor group did not function as intended as some of the supervisors were more interested in getting their groups to make interesting theoretical projects instead of producing a product that was worthy of the satellite. In other words they were more interested in their field of work than the satellite which made it difficult for some of the groups to participate 100% in the project.

Also there were initially a lot of internal support from the various departments of the university but as some departments began to complete some systems while others were still working on more time demanding systems the commitment declined. This was unfortunate as it lead to the problem that when the time for integration came the students responsible for that had to take over the work performed by many of the departments – these had not made provisions to ensure proper backing for final integration and testing of their systems. A possible solution to this could be draw formal contracts at the project definition that commits the different involved parties to their responsibilities.

Another closely related problem was that during the project some students completed their education and left the university while others simply started on other student projects. This meant that some students with key information were often not available during the integration and testing phase which was prolonged due to that fact. This is a very important issue that the management can handle by identifying the different key persons and keeping then involved in the project e.g. by out-sourcing smaller tasks to them as spare-time work. This is particularly easy if there are adequate funds to employ these students to do some to of the work that cannot be categorized into the on-going student projects.

Early in the project the "seeing is believing" idea was used when the mechanical structure was produced as a early prototype to allow the students to actually see the satellite (see figure 6).

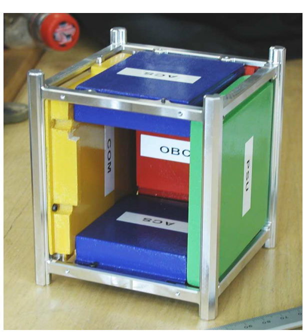

Fig. 6. Early prototype of AAU Cubesat.

This was a huge success as it made the students believe that their work would eventually turn into a satellite.

While the minimum-involvement management did work quite well for the AAU Cubesat project it was afterwards concluded by the students that a larger amount of top-management was needed at the next project. This was due to two things: It sometimes put too large a work pressure and responsibility on the students which made some leave the project before the end. Secondly for it to be successful the right students with the right resources are needed and these are not always available.

Finally two other important lessons was learned from the AAU Cubesat project: The perhaps most important thing is that the interface specifications must be kept updated at all times and changes in interfaces must be discussed in the steering committee. Another important lesson was the Keep It Simple Stupid (KISS) principle is very important to remember when building satellites, complex systems simple consume much more time in the integration phase.

VII. Managing the AAUSAT II Project

Following the relative success of AAU Cubesat in the summer of 2003 then it was promptly decided that Aalborg university should build a new student satellite called AAUSAT II. Work on this began in the autumn semester 2003 and continued in the spring of 2004.

However it quickly became apparent that the project was running astray for two reasons; Firstly no economical means had been secured before the new project was initiated and secondly no clear direction for the new satellite existed, but it was mainly motivated by the high spirits following the launch AAU Cubesat.

A key lesson was learned here: Before a project is committed there must exist a clear picture of the objectives and means to reach them. This does not mean that every detail should be planned in advance, but there must be a clear idea about how the project is funded and hence an idea of a budget, a clear idea idea of what kind of satellite is to be built (envelope and complexity) and finally a schedule leading to a realistic launch date.

AAUSAT II lacked the above for the first year of its development. Therefore in the summer of 2004 the whole project was re-staged by addressing the mentioned areas above and recruiting a large number of new students to increase the level of activity. The management group was also strengthened to four persons in this period by incorporating former AAU Cubesat students, now PhD students at the university, in the group. The final organisation was formed as two parts: The management team, which also acted as supervisors for almost all groups, and the students groups. These two parts then joined in the steering committee called the system engineering group where all four managers and one fixed student for each group which acted as responsible system engineer for his subsystem. However there is one extra seat per group in the system engineering group which the students then take turns at occupy – this system was introduced to ensure that all students got a feeling of the system engineering work while the fixed student from each group ensured continuity.

This reorganisation put the project back on track, but the eagerness of the managers to get things going led to a situation where the project was overmanaged with the effect that the students were too little involved in the system engineering side of the project, which clearly contrasted the first objective. Talking about it at the weekly meetings did little to put the responsibility back on the students, who used the extra resources on their subsystems instead. In the end the management group walked out on the group at a scheduled review to kick-start things - This gave the student the sensation that it in fact was their project and they stepped up and took the responsibility.

The example, contrasted with AAU Cubesat, clearly demonstrate the major challenge of managing a student satellite; It is a very fine line between undermanaging and overmanaging. As we have learned then the good student satellite manager has a very large overview of the project and communicates a lot with the students about their problems and solutions, but does not jump in any time he thinks the students are walking a bit away from the straight path - most times the students find back themselves and learn from it.

The main management tasks, as it has been exercised on the AAUSAT II project since the mentioned design review, is to keep a cool overview and manage the budget, perform the launch negotiations and communicate with the students as one engineer to his peers. However, from time to time situations arises were the management group sees important problems that must be solved. These problems can be communicated to the students which in many cases can handle them when aware, other times the management group may lend its manpower to help solve a specific problem alongside the students - manpower is often the most scarce resource in this kind of project.

At times during the AAUSAT II project it has been hard for the students to maintain focus. Specifically, and not surprisingly, in periods with many exams. One effective tool that have been employed here is to refocus the group after the last exam in a period by making a long weekend workshop with scheduled discussions on key areas and practical work in the laboratory. Such workshops brings students together, strength the team spirit and all in all gives a large step forward to the project.

VIII. Conclusion

In this article the evolution of the organisation and management of the two student satellite projects at Aalborg University has been discussed. This included a presentation of the two satellites and an introduction to the Problem Based Learning method used at Aalborg University. As an overall conclusion the following set of recommendations can be summed up:

- Ensure that a large part of the needed funds are available before project start.
- Ensure that the different involved parties will support the project even through difficult times.
- Keep the interface specifications under a very tight leash. Force the students to keep them updated and all changes should be discussed in the system-engineering group.
- Allow the students to make mistakes, do not overmanage the project.
- Start launch negotiations from the start of the project as this provides the project with needed realism. It makes the students (and managers) believe in the project.
- Use techniques to make the students feel like a team.
- Seeing is believing - make some kind of simple mechanical prototype early in the project.
- Use workshops where as many as possible of the students are gathered at one time, e.g. over a weekend.
- Remember the KISS principle and adhere to it.
- Integration always takes more time than anyone expect. Transpiration follows inspiration.

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