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EDUCATIONAL BENEFITS FROM THE AAU-CUBESAT STUDENT SATELLITE PROJECT

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Abstract

On the 30th of June 2003 a former Russian ICBM carrying the first batch of satellites build around the cubesat pico-satellite concept, as described by professor Bob Twiggs at Stanford university, deployed its payload in Earth orbit.

One of these is the AAU-cubesat, which is build at Aalborg university in Denmark by students from various departments within the natural sciences. The mission of the satellite is to use the on-board camera to take pictures of the surface of the Earth, both as a public outreach mission and secondly, if the picture quality allows, as a mean to track algae movements in the seas. But apart from the scientific mission the main purpose has been to use the project as a "hands-on" project for education.

From its start the project has been handled entirely by the students with only a secretary attached for economical management and other paperwork, as well as a project responsible supervisor to oversee the efforts and react if required.

The paper describes the various benefits of this project in more detail focusing on: Overall project management and coordination, the technical projects, the "large project" benefits. And also examples of the pitfalls encountered during the AAU-cubesat project are given.

1 Introduction

In the summer of 2001 it was decided to initiate the AAU-Cubesat project at Aalborg University in Denmark. The idea was to let engineering students from various departments cooperate in the completion of a very large project and thereby give them a unique chance to participate in a project that not only needs good engineering skills, but also the skills to solve problems that are inter-disciplinary of nature.

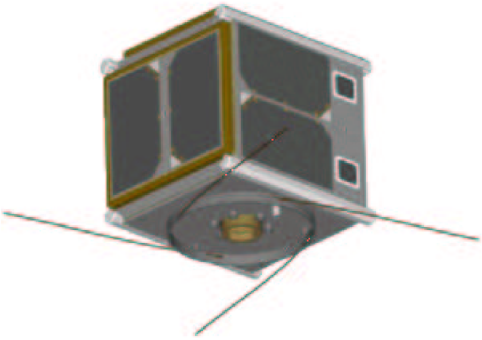

Figure 1: Picture of AAU-cubesat rendered from mechanical models, antennas in the deployed configuration

This project was made possible due to the cubesat concept, which has been developed at Stanford University and California polytechnic institute led by professor Bob Twiggs [3]. This concept allows a satellite of dimensions 10x10x10cm and mass 1kg to be launched into low Earth Orbit at a total launch cost of about $40,000. A rendered picture of the completed satellite can be seen on figure 1.

The project has through its 1.5 years lifetime in-

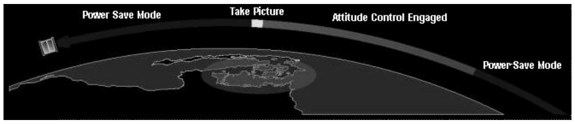

Figure 2: Illustration of the mission concept

volved approximately 80 students from the following branches of engineering: computer science, electronic engineering, mechanical engineering and control engineering. All getting the chance to be involved in a unique "hands-on" project, with the very motivating perspective getting their work launched into space.

This paper will describe the various educational benefits that this project has provided for the students involved and it will describe the pitfalls of this project, such that they can be avoided in future similar projects.

The next sections will at first, as an introduction, describe the satellite and its mission. Hereafter an introduction to the special problem oriented and group centered educational form practiced at Aalborg university is given in order to facilitate better understanding on how the project-work has been carried out. This is followed by a description of the overall project organization and a description of project management throughout the project. At last an update on the project outcome following launch is given.

2 Project Success Criteria

In the initial period of the project it was decided by the students involved that the scientific mission of the project should be Earth Observation and many ideas were under consideration, but they were all found to be to technical challenging to implement on a platform as small as a the cubesat. In the end it was decided to fly a camera without a specific scientific purpose for it, but use it primarily as a public outreach mission by letting the public vote for camera targets on the project web-site, and secondly find scientific uses of it, based on the actual performance experienced. One of these scientific uses could be to track algae movements in the oceans.

However, as this project was to be developed by students with no previous experience with design of space-rated systems it was agreed to define the project success criteria in an incremental manner, as can be seen from the following list of success criteria:

1. Education of engineers, practical experience with space systems
2. Acquire a signal from the satellite
3. Acquire comprehensive housekeeping data for system evaluation
4. Use the camera for public outreach mission and scientific missions.

Using this definition the project will still be a partly success even though no signal is ever received from the satellite. A conceptual illustration of the nominal mission scenario is depicted in figure 2.

3 The AAU-Cubesat Satellite

The following will provide an overview of the satellite from a technical perspective. The aim is to facilitate an overview of the various subsystems in a student satellite and the engineering skills and disciplines required to build such a satellite.

As already described the satellite has dimensions 10x10x10cm and mass 1 kg. The satellite consists of 5 electrical subsystems, these are:

- PSU: Power Supply Unit
- OBC: On Board Computer
- ADCS: Attitude Determination and Control System
- COM: Communication system
- CAM: Camera - the payload

In addition to these electrical subsystems the satellite consists of the structural subsystem, and a ground segment has also been developed for the project. The following paragraphs will describe each part in a little more detail. For more information on the technological part of the project consult the project home-page [1].

3.1 Power Supply Unit

The PSU consists of solar panels, electronics and batteries. The chosen solar panels are triple junction cells at an efficiency of 27% thus providing a conservative estimated average input power of about 1.4 W. This power input constitutes one of the major constraints in the design and has been the driving force behind many design decisions.

To acquire the maximum power input the electronics controlling the PSU must actively perform Maximum Power Point Tracking (MPPT) to control the solar-panel voltages and currents for a maximal power output. This is done using a small microcontroller.

The acquired energy is either consumed by the other subsystems or stored in the batterypack that consists of four 900 mAh Lithium-Ion cells. In addition to the main task of energy conversion and storage the PSU collects various housekeeping data and transmits them to the OBC over an I2C-bus that connects the different subsystems. Finally the PSU is responsible for securing the other subsystems against latch-up events.

3.2 On Board Computer

The OBC is a custom built micro computer build around an Infenion C167 processor running at 10 MHz. The software running on the microcomputer has the following responsibilities:

- Collects and store all housekeeping data, as well as pictures taken by the camera
- Maintains a flightplan and executes flightplan events
- Performs various algorithms for the ACDS system
- Implements the communication protocol and drivers for COM-hardware

In addition the OBC provides the possibility of uploading new OBC software into the on-board Flash-ROM (While not erasing the original flight software placed in PROM)

3.3 Attitude Determination and Control System

In order to be able to take pictures of specific locations on the Earth the AAU-cubesat features an ACDS system. It calculates the orientation of the satellite in respect to the sun using both magnetometers and sunsensors mounted on each side.

Using this information in conjunction with a model of the satellites' orbit around Earth it is able to change its attitude such that it points at desired locations on the surface of the Earth. This is done using three electro-magnetic coils that is used to "push" on the magnetic field of the Earth.

The ACDS system has its own dedicated PIC-controller that performs most of the work autonomously. However, due the rather complex algorithms involved, the OBC performs some of the algorithms for the ADCS system. The two systems communicate using the I2C-bus.

3.4 Communication System

The communication systems is controlled from the OBC and it consists of a MX909 packet modem and a SX-450 telemetry radio. In addition the AX25 protocol for amateur packet radio is implemented on the OBC.

The radio transmits at a power of 0.5 W and the modem outputs a GMSK modulated signal with a data-rate of 9600 Baud. The radio output is transmitted using two dipole antennas and the frequency used is 437.450 MHz. This frequency has been obtained through the Amateur satellite association AMSAT. The worst case link margin has been calculated to 10.7dB.

When launched on the rocket the antennas are folded to the structure of the satellite and when the satellite is deployed from the launcher it deploys the antennas using burn resistors that breaks a plastic wire. This mechanism constitutes the only actuating mechanical systems on the satellite.

Given the bandwidth provided by the COM system it is expected that it is possible to acquire a new picture taken by the camera every second day, while still leaving bandwidth to acquire housekeeping information and command the satellite.

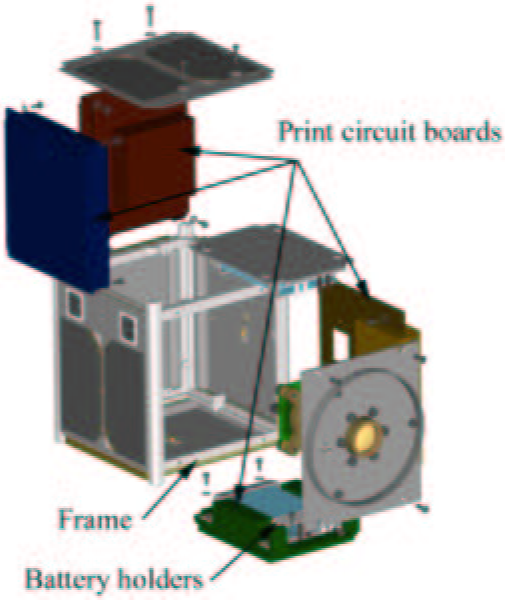

Figure 3: The satellite structure, exploded view

3.5 Camera

The camera is based around a Kodac CMOS image sensor that provides a resolution of 1280x1024 pixels in 24bit colors. The lens systems for the camera has been customly built for this project and it will provide an on ground resolution of approximately 150x120 meter from a 900 km orbit. The obtainable resolution was primarily limited by optics size constraints.

The camera receives commands through the I2C-bus and transfers pictures directly to the OBC memory through a parallel DMA interface.

3.6 Mechanical Structure

The structural system consists of a frame cut from one piece of aluminum and side panels made in carbonfibres to conserve mass. Also in order to conserve mass the electro-magnetic coils are implemented as part of the structure.

The internal structural composition is such that the camera lens-systems is mounted on the middle of one side of the satellite with the lens occupying the center of the satellite. On the remaining five sides print boards are positioned. An exploded view of the satellite main structures can be seen on figure 3

3.7 Ground Segment

The ground segment that has been developed for the project consists of a tracking antenna, an off-the-shelf amateur radio, a modem similar to that on the satellite and a PC. The software on the PC is capable of controlling the satellite autonomously, i.e. acquire signal, download housekeeping data and upload new flightplans, or it can be operated by an operator. All downloaded data are stored in a central database.

4 Problem Oriented Group Work

At Aalborg University the curriculum is taught very differently than what is normal for most engineering universities. To understand how the AAU-cubesat was developed and to understand how work was organized, it is important to have some knowledge of the educational form at the university. This section will provide such an overview.

At the start of each semester the engineering students are told to form groups of about 5 people, who wish to work on a particular project they can chose from a set of proposed projects for that particular semester. About two thirds of the curriculum is then spend working on that particular project, while the remaining third of the curriculum consists of ordinary classes and problem solving. These classes usually ends with a written exam, while the project report is to be defended by the group at an oral examination that results in individual grades.

The main benefits of this scheme can be listed as:

1. High degree of student motivation, initiative and creativity
2. The projects are problem oriented and often defined in cooperation with local industry and therefore highly relevant
3. In addition to training engineering skills, planning and cooperation skills are trained as part of the process

Each student group is attached to a supervisor that reviews the work performed by the group and through dialog with the group helps address problems related to the project. At the end of the semester a project report of about 150 pages is handed in for evaluation, and is then defended by the group at an oral examination.

These semesterprojects have been the foundation for all the work performed in connection with realization of AAU-cubesat. For a more in depth explanation of this educational concept, see[2].

5 Organization and Planning

The following will describe how the project has been organized and how planning throughout the project has been handled. The whole period can be divided in two main phases: a definition and development phase and an integration and test phase. As the organization and planning processes changed dramatically at the transition to the second phase these will be described separately. The duration of each phase have been one year, i.e. the whole project was completed within two years.

5.1 Definition and Development Phase

Initial a project catalog was presented by the professors/teachers who took the initiative to initiate the AAU-cubesat project. This project catalog did not consider the satellite's payload and mission, but only the satellite platform. These projects were then, competing with ordinary project proposals, chosen by different groups at the semesters where they were offered. A list of these projects and the duration (in half year semesters) are presented in table 1[1].

All in all approximately 50 students started working to develop the AAU-cubesat. As can be seen from the table, no groups were formed to build any communication hardware. This was due to the fact that none of the institutes involved had any knowledge in this field. It was therefore decided to by the communication hardware from a company that offered a full solution fit for the cubesat concept. The different groups were formed from students from the following departments/institutes of the university, again demonstrating the inherent interdisciplinarity in this kind of project:

- Mechanical engineering
- Control engineering
- Electrical engineering
- Power systems
- Computer science

Following project selection a plenary meeting was held with all participants. This meeting, which had no predetermined agenda, started out with a lot of rather confused students discussion the aims and organization of the project. In the end a structure, as indicated on figure 4, for the whole project organization was determined by the students. The structure contains three bodies: the various project groups, the group of supervisors and a steering committee.

Title	**Length**
Mechanical Structure	2
Attitude Determination	2
Attitude Control	2
Power supply unit	1
On-board computer and payload	1
Data handling and control	1
Web-based Ground SW	1
On Board Communication Protocols	1
Virtual Control Room	1
Automated Software Testing Tool	1

Table 1: Table of initial projects in the AAU-cubesat project

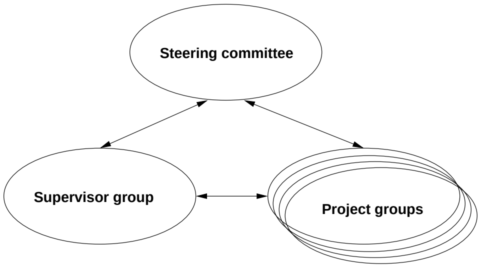

Figure 4: The organizational structure

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[1] Some of the projects have been run by multiple project groups in parallel

The student led steering committee was organized with one representative from each project group and the professor acting as overall project supervisor. The steering committee held weekly meetings, with the following objectives:

- Define mission and payload and top level interfaces
- Oversee and discuss group projects
- Discuss and determine subsystem level interfaces
- Ensure that loose threads was picked up

In addition to the students and the project supervisor additional supervisors were present at the meeting when appropriate for the particular discussion.

Further to review the process and to give all students overview of the situation three formal design reviews were held, the first in November 2001, the second in May 2002 and the third in January 2003. At these reviews all groups presented the status of their work and timeline for completion of the particular subsystems. All presentation were followed by round of questions aiming mainly at addressing weak points in the design and discussing issues relating to the integration phase.

By February 2002 all the one-semesterprojects handed in reports as well as nearly complete subsystems/components to be ready for integration. Some subsystems, however, required more work and interested students from the one-semester groups were then assigned to complete that work as a spare time effort, while the two-semester groups continued to develop their subsystems.

The steering committee continued to meet and organize throughout the second semester the number of attendees was, however, reduced due to lesser interest from the groups having completed their part.

5.2 Integration and Test Phase

As of July 2002 the "design and development" phase was concluded and focus was shifted to "Integration and test". To boost this phase a group of about 12 key persons from the project groups were hired by the project as student helpers during the summer break at the university. Then at the start of the semester, September 2002, the following work items remained:

- Development of a radio solution (hired company failed to deliver)
- Further integration and software adjustments
- Final print board manufacturing
- Satellite assembling
- Environmental testing
- Development of ground station

As all these items needed thoroughly knowledge of the complete satellite system, it was only possible to establish one group, of five persons, to work full time with the satellite integration and testing effort. Other persons were then included to do various specific tasks as spare time work.

For the one group working full time it became hard work indeed, especially as the contracted company for the radio solution failed to deliver, but it also gave the group an unique opportunity at, as part of university studies, working with a real and complex system and getting it to work satisfying rigorous requirements. In addition the group also gained tremendous experience within this period at working together with other actors interested in the project, as the group was responsible for all external contact, including:

- Component and PCB manufactures
- Coordination regarding access to environmental test equipment
- Launch coordination with other participating universities and launch provider
- People from all branches of the press (written, TV, radio)

When the semester concluded in January 2003 only the following issues remained:

- Assembling of the flight model including solving problems with solar cell assembling
- Minor software adjustments

- Camera calibration
- Continued functional- and environmental testing

It was not possible to compact these issues into a semester project that would fulfill the requirements for theoretically work as part of the project, and the remaining tasks were therefore solved as spare time work mainly by the group working full time the previous semester.

Due to the amount of work involved this made it a very hard semester for that group, but again it provided an unique opportunity for the group with many educational benefits as well.

The satellite was completed in April 2003 and was transported to Canada, together with three students, to undergo environmental qualification tests together with the other satellites to be deployed from the same deployment mechanism. From Canada it was transported to Plesetsk in Russia, where it was functionally tested and the batteries were conditioned (two students were sent to the location) before the launch.

6 Lessons Learned

So far this paper has described how the organization has worked during the project; In general the sketched approach has been working well, but there are of course room for improvement. This section will summarize some of the problems identified during the project and describe possible solutions.

6.1 Proper Backing for the Project

Initially there were a lot of internal support from the various departments of the university for the project, but as time progressed and some departments concluded work on their parts, while others still worked on the more time demanding parts, the commitment from these departments declined, and in the end the effort of integrating and completing the satellite was driven by one department only.

This was unfortunate, because it made fund-raising more difficult and put a large strain on the students responsible for integration and testing, because they more or less had to completely take over the work performed by students in other departments, as these departments had not made provisions to ensure proper assistance when integrating their developments on the satellite.

A possible solution, discussed at evaluation meetings, is to on project definition draw formal documents, or contracts, stating the responsibilities from start to end of the project. All participating departments must then agree to commit itself to these responsibilities.

6.2 Students Leaving the Project

Due to the fact that the all the student projects started simultaneously, but were of different length, and due to the fact that some students completed their education (and thus left the university, during the project) many students with key information needed for integration and testing were no longer part of the project when the integration effort started.

There was contact with these people, but as they of course were busy with other student projects or work then the integration phase was prolonged due to this. Therefore to counter this as best as possible then a lot of attention in future projects should be focused on how to:

- Design for easy integration, i.e. **very** well defined interfaces
- Make sure end products of the student projects are of integrateable quality, so as remaining issues does not fall back on the integrators
- Make sure that students leaving the project are still somewhat involved by keeping them involved in planning and e.g. by out-sourcing smaller tasks to these students as spare-time work

The latter point is particularly easy if funds are plentiful enough to employ students in their spare time to perform the work that cannot successfully be categorized into the particular on going student projects.

6.3 Outreach

A project like this is a great opportunity for public outreach, as many people find space exploration and utilization very interesting. It is especially easy to sell such a project to the media as it is performed by students and not "professionals". During (and indeed after) the AAU-cubesat project the following kinds of outreach activities took place:

- Various interviews for the media, both written, radio and television
- People (e.g. secondary school classes) coming to visit the laboratories and talk with the students involved
- Various presentations for both the general public and more specialized presentation for e.g. radio amateurs taking interest in the project

During the project these events have been organized in an "ad-hoc" manner and therefore the full outreach potential has not been utilized. Therefore in future projects special attention should be invested in this part of the project. One solution, currently pursued at Aalborg university, is to involve students studying media-science in the project in order to let them define strategies and make sure that they are implemented during the project.

7 Post Launch Update

Following launch on the 30th of June 2003 the satellite has been located and signals are routinely heard from the satellite, and it has been possible to decode some, but not all, of the signals. The following problems have been identified:

- Received signal strengths are far below expected
- Telemetry indicates problems with the power generation and/or battery storage

Simple two-way communication has been established (pinging), but due to the above mentioned problems it has so far been impossible to establish a data-link connection in order to retrieve larger amounts of housekeeping data.

The phase following the launch also showed it self to be highly educating for the students involved. Initially, following spacecraft separation from the launch vehicle, all in all 7 small spacecrafts shared roughly the same orbital-parameters, and in the period following a coordinated effort, between all the participating groups and the NORAD tracking radars, managed to sort out the connection between specific parameter sets and corresponding satellites.

The effort of trying to establish a successful datalink connection and understand the problems on the satellite continues, driven by the students responsible for the integration and testing phase. And the project thus continues to provide first class "hands-on" experience for the students involved in solving real-life problems.

8 Conclusion

In conclusion it can be said that while the project as a whole so far has not fulfilled all its success criteria it has been a great success when it comes to fulfilling the first success criterion, namely providing a "hands on" education opportunity for engineers. Particularly this kind of project seems to be well suited for the "Problem Oriented Group Work" educational paradigm used on Aalborg university. For the students involved the main benefits have been:

1. Highly motivating and unique experience
2. Relevant and challenging problems for project work
3. Experience with dealing with inter-disciplinary problems
4. Experience with inter-projectgroup coordination and large scale project management

Through its life-time the project has demonstrated that the "Hands On" approach has been very beneficial for the students. Both because the projects defined within this context have been technical challenging, but also because of the motivation factor that has motivated the students to put in many more working hours compared to a normal project, and further due to the fact that students have involved themselves in their spare time after completion of the individual projects in order to help integrate their system in the complete satellite.

Another thing that has become evident through this kind of project is that with this type of project where the parts need to be 100% perfect before they are finished gives the students a good opportunity to gain practical experience, compared to a "normal" university engineering project where the result usually is a kind of working prototype model.

At Aalborg university the AAU-cubesat project will be followed by a similar satellite project, currently under definition, that will build on the experience gained so far, both technically and organizational. An integral part of this project will be to hand over knowledge from the "old" students to the new project groups taking over.

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