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The SSETI-express Mission: From Idea to Launch in one and a Half Year

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Abstract. *In January 2004 a group of students met at the European Space Technology and Research Centre (ESTEC) in Holland to discuss the feasibility of building a micro-satellite, dubbed SSETI-Express, from parts derived from other student satellite projects and launch it within one and a half year. The project is an initiative under the ESA Education Department and the Student Space Exploration and Technology Initiative (SSETI)[3], an European student organisation. The satellite is currently scheduled for launch on the 30th of June 2005 atop a "Cosmos" launch vehicle from Plesetsk in Russia.*

This paper provides a description of the organisation behind the project and the mission of the satellite. Further it provides a technical overview of both the space segment and the ground segment together with key lessons learnt from the process of building a student satellite with widely distributed teams.

Keywords

Student satellite, distributed development, component reuse, technology demonstration.

1 Introduction

In January 2004 a group of students met at the European Space Technology and Research Centre (ESTEC) in Holland to discuss the feasibility of building a micro-satellite, dubbed SSETI-Express, from parts derived from other student satellite projects and launch it within one and a half year. The project is an initiative under the ESA Education Department and the Student Space Exploration and Technology Initiative (SSETI)[3], an European student organisation. The satellite is currently scheduled for launch on the 30th of June 2005 atop a "Cosmos" launch vehicle from Plesetsk in Russia.

The design relies heavily on its sister project SSETI-ESEO (European Student Earth Orbiter), which is a much more complex satellite that has been developed by students since the year 2000. From the current SSETI-ESEO design SSETI-Express has derived the mechanical design, Electrical Power System and Propulsion System. It is a key objective of the mission to evaluate these systems prior to the launch of ESEO. The envelope of the satellite is 60x60x80 cm and 80 kg.

The AMateur SATellite organisation (AMSAT) supplies both an UHF band as well as a S-band radio for the satellite. These can be used separately as telemetry and telecommand transceivers, or be combined to act as a voice transponder as a service to the radio amateur community.

In addition the satellite carries a small camera, which will be able to take colour pictures of the Earth as well as celestial targets. The camera is the original engineering model from the AAU-Cubesat project [1].

Finally the satellite itself carries three cubesat payloads which will be released from SSETI-Express satellite shortly after separation from the launch vehicle. A picture of the satellite during final integrations can be seen on figure 1

The paper is organised as follows; Firstly the organisation behind the SSETI-Express satellite project is described, then the mission and mission phases are described, hereafter an overview is provided of all the subsystems that makes up the satellite and the ground infrastructure. Finally the key lessons learnt from the undertaking of this first-of-a-kind project is provided, focusing on the challenges of adopting existing hardware into a real mission given the distribution of the development team and the tight schedule.

This paper focuses on the technical aspects of the project while a companion paper [2] will provide more insight into the managerial and programmatic side of the project. '

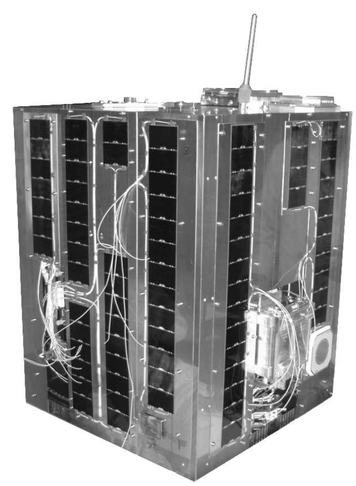

Figure 1. SSETI-express photographed during final integration

2 Mission

The mission baseline has been to build the spacecraft around systems developed by students at local universities, emphasis has been put on systems which had already seen considerably development to be able to focus on system engineering and integration rather than subsystem development throughout the project. From this basis a platform has been defined together with a number of payloads. The payloads are a colour camera, an experimental propulsion system, and experimental S-Band antennas. In addition the radio system on the satellite will work as a voice transponder for the radio-amateur community. Finally three cubesats are deployed from SSETI-Express.

The following subsections will declare the mission statement, enumerate the mission objectives and finally discuss the mission phases that have been foreseen.

2.1 Mission Statement

The following mission statement has been adopted: *"The SSETI Express mission is an educational mission that shall deploy CUBESAT pico-satellites developed by universities, take pictures of Earth, act as a test-bed and technology demonstration for hardware of the complementary project: the European Student Earth Orbiter, and function as an radio transponder for the rest of it's mission duration"* [4]

2.2 Mission Objectives

To accomplish SSETI Express's mission statement, the following objectives have been developed [4]:

1. To demonstrate the successful implementation of this pan-European Educational initiative and therefore encourage, motivate and challenge students to improve their education and literacy in the field of space research and exploration.
2. To carry as passengers, and subsequently deploy, up to three educational CUBESAT pico-satellites. Three cubesats will be deployed by SSETI Express. They will be deployed from a T-Pod developed by UTIAS Space Flight Laboratory, Toronto:
   (a) XI-V from Japan, University of Tokyo
   (b) UWE-1 from Germany, University of Würzburg
   (c) Ncube-2 from Norway, Andoya Rocket Range
3. To demonstrate and test the hardware and technology being developed for the European Student Earth Orbiter.
4. To take pictures of the Earth.
5. To involve the amateur radio community in the downlink of housekeeping and payload data, and support this community by acting as a transponder once the main objectives are complete.

2.3 Mission Phases

Operation of the satellite is categorised into a number of mission phases. These are: Launch and Early Operations (LEOP), Payload Operations and Disposal. See figure 3 [4]. The following will describe the activities in each phase.

Figure 2. The XI-IV Cubesat to be deployed from SSETI-Express

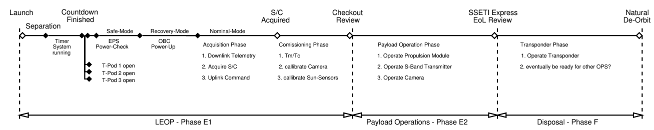

Figure 3. The various phases of the SSETI-express mission

2.3.1 LEOP

In this phase the spacecraft is acquired and functional testing is performed in preparation of the payload operations phase. This phase is expected to last one to two weeks. The phase is initiated by a number of autonomous activities:

1. After a separation delay: deploy the three cubesat payloads
2. The ACDS system will initiate autonomous detumbling of the satellite
3. OBC and UHF will start to transmit a beacon signal every 20 seconds containing vital health information

Hereafter a number of activities will be performed assisted through the mission control centre:

1. Acquire the signal and initiate two-way communication
2. Confirm completion of detumbling, i.e. nominal attitude profile acquired
3. Extensive functional testing of all systems, including:
   - Calibrate ACDS sensors
   - Calibrate camera gains

Upon completion of the above activities operations will continue in Payload Operations mode.

2.3.2 Payload Operations

Based on spacecraft health and input from the payload teams then payload activities will be performed. Main payload activities:

1. Photograph interesting sites on the Northern hemisphere

2. Perform PROP tests (joint PROP and ACDS activity)
3. Use S-band transceiver to characterise performance of S-band patch antennas

This phase is expected to last about a month at full focus, hereafter the operations plan will be reevaluated.

2.3.3 Disposal

When payload operations have completed then the satellite will work as a voice transponder between UHF and S-band for radio amateurs. This phase will last as long as the spacecraft is alive. The spacecraft is disposed of by natural orbit decay.

3 Organisation and Schedule

This section will describe the organisation behind the project, the involved teams and the project schedule and progress. Backing the project are two main organisations; The ESA education office provides general management, access to workshops and testing facilities at ESTEC and economical means for integration, testing and launch. The Student Space Exploration and Technology Initiative is a self governing student organisation that organises the different teams, which work on SSETI-Express (and other SSETI satellites).

The teams reside at local universities which endorse their involvement in the project and help funding the individual subsystems as developed at the universities. The teams are grouped in three groups: Space segment, ground segment, and the Management, Integration and Testing (MIT) segment.

3.1 Space Segment Teams

The following table list the teams, their name, task and location, which are involved with work on the space segment of the mission.

Team	System	Location(s)
ACDS	Attitude Control and Determination	Aalborg, Denmark
CAM	Camera Payload	Aalborg, Denmark
EPS	Electrical Power System	Napoli, Italy
OBC	Computer and Datahandling	Aalborg, Denmark
PROP	Propulsion Payload	Stuttgart, Germany Lausanne, Switzerland
SBAND	S-band payload transceiver	Warsaw, Poland AMSAT, United Kingdom
TCS	Thermal Control System	Stuttgart, Germany
UHF	UHF Transceiver	Hohenbraun, Germany Vienna Austria

3.2 Ground Segment Teams

The following table list the teams, their name, task and location, which are involved with work on the ground segment of the mission. The main groundstation is located in Aalborg in Denmark, but the mission also have limited access to a groundstation placed at Svalbard in Norway.

The operations centre is also placed in Aalborg for the initial operations, hereafter it will relocated to Wroclaw in Poland. Downlinked telemetry is stored in three different locations: Aalborg (raw data), Vienna (processed data) and Paris (Public data).

Team	System	Location(s)
TIDB	Data storage and distribution	Paris, France
INFRA	Data publishing	Vienna, Austria
GNDST	Groundstation UHF & S-band	Aalborg, Denmark
MCC	Mission Control Centre	Aalborg, Denmark
OPER	Operations	Wroclaw, Poland

3.3 Management, Integration and Testing Segment

The following table list the teams, their name, task and location, which are involved with MIT work. All subsystem inter-integration work has been carried out at ESTEC under close supervision of the appointed manager from the ESA Education Office, who has also been closely involved in systems engineering.

Team	System	Location(s)
AIV	Assembly, Integration, Verification	Noordwijk, Holland
MAN	Overall Management	Noordwijk, Holland
MIAS	Mission Analysis	Zaragosa, Spain
SYS	Systems Engineering	Stuttgart, Germany Noordwijk, Holland

3.4 Schedule and Progress

Following the ”kick-off-meeting” in January 2004 then the system definition phase lasted throughout the spring of 2004 and was conducted as a spiralling process with increasing level of refinement. The phase was facilitated by weekly meetings using Internet Relay Chat (IRC), newsgroups for detailed discussions, and two intensive workshops where participants had the chance to discuss face-to-face.

In parallel the individual teams worked hard to refine and mature the hardware and software systems. For some subsystems it was impossible to find suitable hardware which had already seen considerable development; therefore also a few complete new developments were undertaken.

Starting in the early summer of 2004 subsystems have been delivered to ESTEC where the integration effort has been an on-going incremental process until March 2005 from whence system level testing has been the major activity. The integration work has primarily been supported by the teams sending people to ESTEC to perform the work under close supervision from the project coordinator of the ESA Education Office.

Status medio April 2005 is that the satellite is completely integrated and has cleared functional testing as well as EMC testing. Vibrations tests and thermal vacuum test still remains.

4 Space Segment

This section will provide an overview of the space segment of the mission. Figure 4 [4] shows the various functional elements and the following paragraphs will describe each of them in some detail.

4.1 Electrical Power System

The Electrical Power System (EPS) receives power from 150 body-mounted double junction GaAs photovoltaic cells, which

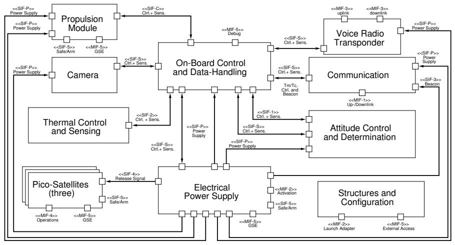

Figure 4. Block overviews of the space segment and functional interfaces

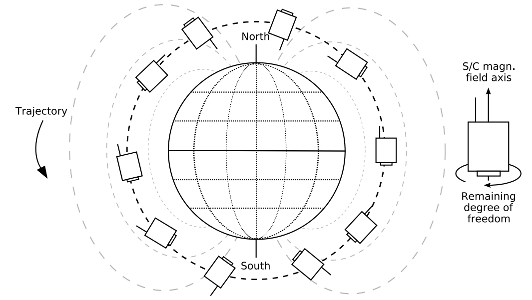

Figure 5. Visualisation of the flight attitude profile

are organised in strings of 15 cells in series. This gives two opposite sides with two strings, two with three and neither the top plate or the base-plate have any strings.

The incoming power, typically around 20W, is conditioned to 28V using a voltage regulator on the input. Connected to the powerbus is a 24V 6.8Ah Lithium Ion battery which is connected through a step-down charging circuit and a step up discharging circuit.

From the powerbus EPS delivers 8 power lines each with latch-up protection. Further EPS is responsible for the satellite power up sequence and an OBC keep alive watchdog.

4.2 On Board Computer and Datahandling

The on-board computer consists of an ARM-7 processor equipped with 2 Mb RAM, 1 Mb ROM and 4 Mb FLASH. All communication to other subsystems is through RS-232 lines configured in a star network.

The datahandling software is centred around an event queue and a filesystem that stores telemetry in RAM and FLASH. Time tagged commands can be uploaded to the satellite and the commands are then put in the event queue ordered after time.

4.3 Attitude Control and Determination

The attitude control and determination system is a completely new development for the mission. To allow quick development then a simple approach was chosen; For attitude control the satellite has a bar magnet aligned with the longitudinal axis of the spacecraft such that the camera and antennas will be roughly nadir pointing over the northern hemisphere. See figure 5 [4].

To reduce oscillations around the directions of the magnetic field lines, due to excess kinetic energy, then two coils perpendicular to the bar magnet and each other are employed to dampen the oscillations using the simple and robust b-dot control law.

A consequence of this control strategy is that rotation about the longitudinal axis is not controllable. In practise this will not be a problem as gyroscopic coupling will in effect make the velocity around that axis weakly controllable and thus inhibit high angular rates.

On-line attitude determination is not required for the above control strategy, but attitude data from an on-board magnetometer and experimental MEMS two-axis sun-sensors are stored in the telemetry stream and used to reconstruct the attitude off-line using an extended Kalman filter.

4.4 UHF Transceiver

The UHF transceiver is the main communications channel for SSETI-Express. It communicates via the AX.25 protocol encapsulated in 9600baud FSK signals. Only the "connectionless" part of the protocol has been used in an effort to keep the communication interface simple.

The frequency, which has been coordinated through AMSAT, is in the 435-438 MHz band, and the transmitted power is 3 W. A single monopole antenna is used which in fact is a modified spare antenna from the METOP series of satellites.

In line with the objectives of the mission then radio amateurs will be involved in both acquiring telemetry from the satellite and commanding it.

4.5 Propulsion Payload

The propulsion payload "PROP" is the most massive and complicated system on SSETI-Express. It will act as an demonstration version of the system for the upcoming launch of SSETI-ESEO. The system is a cold gas system utilising nitrogen as the propellant.

The system contains a propellant tank that keeps the propellant at an initial 300bar of pressure, a pressure management system (including a Pyro-valve) and two thruster clusters with two thrusters each. See figure 6. Each thruster can be controlled independently and each provides 130mN of thrust when activated. The minimum impulse time is 40 ms.

In orbit experiments will be conducted with PROP in order to: Check for leakage, characterise the thrust, experiment with ground assisted closed loop manoeuvres using ACDS.

4.6 Thermal Control System

SSETI-Express does not employ active thermal control, but the thermal analysis of the craft has lead to a number of passive

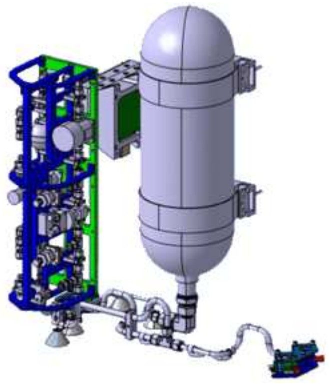

Figure 6. Rendering of the PROP system; Propellant tank with pressure management system and one thruster cluster shown

thermal control means to be implemented, e.g. internal black paint as well as a carefully positioning of subsystems.

A number of thermal sensors are mounted in the structure which will be used to evaluate the correspondence between the thermal model and the actual temperature in orbit.

4.7 Structure and Mechanics

The primary structure has been adopted from the SSETI-ESEO project. It consists of a panel configuration similar to a game-board of tic-tac-toe, see figure 7. Only the shear panels are load bearing, together with the top and bottom plate, while the lateral panels are used for mounting solar panels, attitude sensors and patch antennas. The ASAP-5 seperation mechanism is mounted to the bottom plate and ensures a uniform insertion launch loads into the structure. All load bearing panels are made from alumium honeycomb, while the side panels are thin alumium panels.

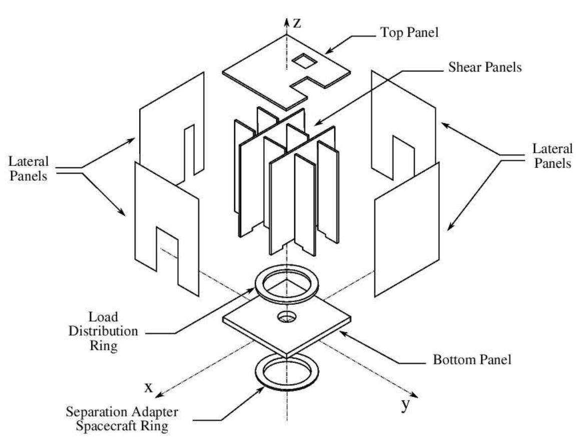

Figure 7. Exploded view of the structure

4.8 Camera Payload

The camera which is flown is in fact the engineering model for the AAU-Cubesat satellite which was launched in 2003 [1]. The camera is based around a Kodac CMOS image sensor that provides a resolution of 1280x1024 pixels in 24 bit colours. The lens system will provide an on ground resolution of approximately 100x100 meter from a 650 km orbit. A picture of the lens and camera system can be seen on figure 8.

Figure 8. The camera system as adopted from AAU-Cubesat

The camera is only turned on while taking the picture. Pictures are always taken in full resolution, but it is possible to downlink a thumbnail version of the picture before beginning to download the complete picture. It is possible to configure various camera parameters in orbit, e.g. integration time and colour gains.

4.9 S-band Payload

The S-band systems consists of 3 experimental patch antennas and a S-band voice and data transceiver supplied by AMSAT-UK. The main purpose of the system is to characterise the performance of the antennas, but the system also serves as a redundant data channel and can be used download telemetry at 38.4kbaud. The transmitted power is 3W.

Finally, in periods where the satellite is not operated by its designers then S-band and UHF forms a voice transponder system for the benefit of the radio amateur community.

4.10 Orbital Cubesat Deployer

Finally SSETI-Express is equipped with three deployers for the cubesat passengers. Rather than the standard P-POD deployer offered from Stanford University and California Technical University, which deploys three cubesats, then three T-POD supplied from university of Toronto have been used. See figure 9.

After separation from the upper stage there will be 74 minutes of delay before the cubesats are deployed this is to minimise the chance of a collision between the cubesat passengers and the other satellites on the launch.

5 Ground segment

An overview of the ground segment is given in figure 10 [4]. The primary UHF and S-band ground stations are situated in

Figure 9. The TPOD orbital deployers as supplied from UTIAS

Aalborg in Denmark and the project also have limited access to a UHF groundstation in Svalbard in Norway.

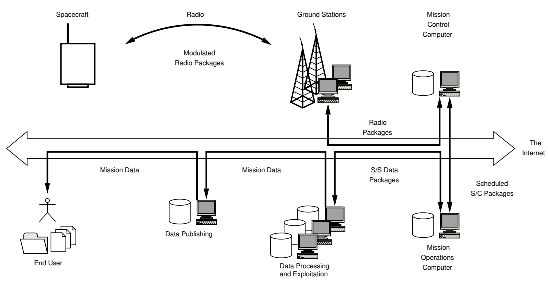

Figure 10. Layout of the ground segment

The "mission control computer" and "mission operations computer" is implemented by the MCC team. The former as a server placed in Aalborg and the latter an Java application that can be loaded and run everywhere. Initially operations will be controlled from Aalborg in order to be close to the groundstation, but when initial operations have completed then the operations will be performed by the OPER team in Wroclaw in Poland.

Processed mission data is stored in Vienna, but in Paris a special version of the database will be kept together with a web-site that allows everyone to extract processed telemetry, so that interested people can see temperatures etc. from the spacecraft. This information will also be of great benefit for other student satellite mission as they can see what to expect when they launch their satellites.

6 Lessons Learned

This section will list some key lessons learned during this distributed student development project.

1. Although disliked by most students and engineers, proper documentation (e.g. interface documents, specifications, work package agreements) from the beginning is vital to a distributed project. The physical distance between the designers as well as the volunteer and spare-time character of the mission make a reliable repository of design decisions and top-level specifications a must. The maintenance of this repository requires discipline and awareness from the designers.
2. Even thorough backing of the sub-system design by the system engineering cannot prevent vast changes in budgets during the design. Necessary ad-hoc design changes during assembly and testing cannot be foreseen and might have huge impact on system wide elements (e.g. thermal, grounding, scheduling).
3. Keeping the design participants' discipline at the required level is a must for all participants. Even if tempting design changes subjectively seem to be tiny, they shouldn't be applied after an agreement on a system baseline was made (see lesson learned number one and two). The mediation of this requirement to the participants is a difficult and sensitive task.
4. However, this project has been characterised by flexibility and deciding things as the project has proceeded. Had the above lessons learned been applied fully to this project then the satellite would not have been completed on schedule.
5. The priciple of keeping things simple cannot be overstated. This applies equally well to designs, procedures, the organisation and documentation. However, in practice it seems to be much more challenging to invent simple solutions than a complex one. A question one should always ask is: "Is this really necessary or just nice to have?".

7 Conclusion

This paper has provided an overview of the SSETI-Express student satellite, its mission and the ground infrastructure. Further, it has provided a number of key lessons learnt throughout this unique project.

To the authors best knowledge then this satellite is the first student satellite to be developed in a distributed international environment and despite whatever flight results will be gained then the project has demonstrated that it is indeed possible on this basis to design, integrate and test a satellite, to a level where it can be flown on a real mission.

All the experience gained in the process will be fed back to parallel SSETI-projects in order in order to improve the designs and craftsmanship of future European student satellites.

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