5th European CubeSat Symposium

3 – 5 June 2013

Ecole Royale Militaire, Brussels

Book of Abstracts

Editor: R. Reinhard
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Rhode-Saint-Genèse (Brussels), Belgium

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Foreword

The low cost of developing and launching a CubeSat has opened the possibility of bringing CubeSats as educational tools into the classrooms of many universities and even some high schools. Unlike larger projects, the short development time for CubeSats of typically two years from the beginning of funding until delivery of the fully-tested flight model is very compatible with the duration of Master and PhD theses. As educational hands-on projects CubeSats are ideal and it is, therefore, no surprise that the CubeSat community is rapidly growing. The CubeSat Standard was defined in 1999 by Stanford University and California Polytechnic State University. Now, only 14 years later, about 300 CubeSats worldwide have already been launched or are in different stages of development.

CubeSats are very attractive because of their low cost, their short development time and the CubeSat Standard. Standard satellite structures for different applications and payloads have been suggested many times for larger satellites in an attempt to lower the cost but all these attempts have failed. For CubeSats, standard satellite structures and deployers are the norm. This has helped to keep the cost for CubeSats low, allows to purchase space-qualified standard CubeSat subsystems from specialized CubeSat shops at affordable prices and has the further advantage of flexible launch opportunities. In principle, a CubeSat can be exchanged as late as a few months before launch by another CubeSat, or the CubeSat can be launched on a different launch vehicle.

CubeSats are traditionally limited in volume, mass, power, data rate and attitude control precision. These limitations are the reasons why, in the past, CubeSats were mostly developed for educational purposes and were not considered for serious applications. Due to major advances in miniaturization in recent years these limitations apply less and less, opening up new possibilities for CubeSats. Examples are various kinds of propulsion, S-band and even X-band for telecommunications, solar panels, drag-free technology, microgravity and biology experiments, atmospheric re-entry, intersatellite telecommunications, high-performance miniaturized star trackers, drag sails for de-orbiting large structures, light-weight composite materials for CubeSat structures, free-flying payloads for planetary exploration. A number of CubeSats can be equipped with common instruments and launched, deployed and operated together as a distributed sensor network for atmospheric or space weather research, for Earth environment monitoring or ship identification and tracking at very low cost.

The propulsion subsystem (thrusters and propellant) on board a CubeSat can be several hundred times lighter than on a large satellite to achieve the same effect. Miniaturized propulsion systems open up the possibilities of formation flying of two CubeSats (now) or up to hundred CubeSats (in the future) in a constellation to address fundamental scientific questions which are inaccessible otherwise. Examples are low-frequency radio astronomy and micro-scale plasma physics in the magnetosphere.

CubeSat reliability is a concern and the risk of a CubeSat malfunctioning is much higher than the risk of failure of a large satellite built to industrial standards with high-quality components and multiple redundancy. The requirement of a reliability approaching 100% has led in the space industry to a conservative attitude which is not conducive for implementing the latest technologies. This is where low-cost

CubeSats come in. Industry is increasingly using CubeSats as low-cost testbeds for trying out innovative technologies. In many cases space industries are partnering with universities in the development of a CubeSat.

More and more launch vehicle providers are beginning to cater for the needs of this emerging new market segment. After accommodating the primary payload of one or several large satellites there is often enough payload capability left to accommodate a few CubeSats as secondary payload, as long as their interfaces are standard and the CubeSats do not have special requirements, e.g. concerning the orbit.

This is already the 5th European CubeSat Symposium. It is intended to hold the European CubeSat Symposia every year in June in Brussels. In the interest of saving travel time and money, the European CubeSat Symposia are being held back to back with one of the biannual QB50 Workshops in Brussels which already attract 120 people from the CubeSat community. QB50 is an approved project involving a network of 50 CubeSats, provided by universities from all over the world, for atmospheric research and technology demonstration planned for launch on a single rocket in 2015. The QB50 Workshops focus on specific project related matters. The Symposia, on the other hand, address a wide range of topics of general interest and provide a forum for presentation and discussion of new technologies. They are open to all CubeSat teams and to people who want to learn more about CubeSats.

Beginning with the 4th European CubeSat Symposium, a specific session structure has been implemented in the Symposium programme. To avoid a large number of rather similar CubeSat presentations, authors were requested not to attempt to describe all aspects of their CubeSat design in a 15-minute presentation. Instead they should focus on the most interesting/novel aspect of their CubeSat design and present that in some detail. If a CubeSat design has several novel aspects, several papers on that particular CubeSat, each focusing on a different novel aspect, should be submitted and given in different sessions. In this way, Symposium participants know exactly which sessions to focus on if they want to learn more about specific topics and who to talk to if they want to know more.

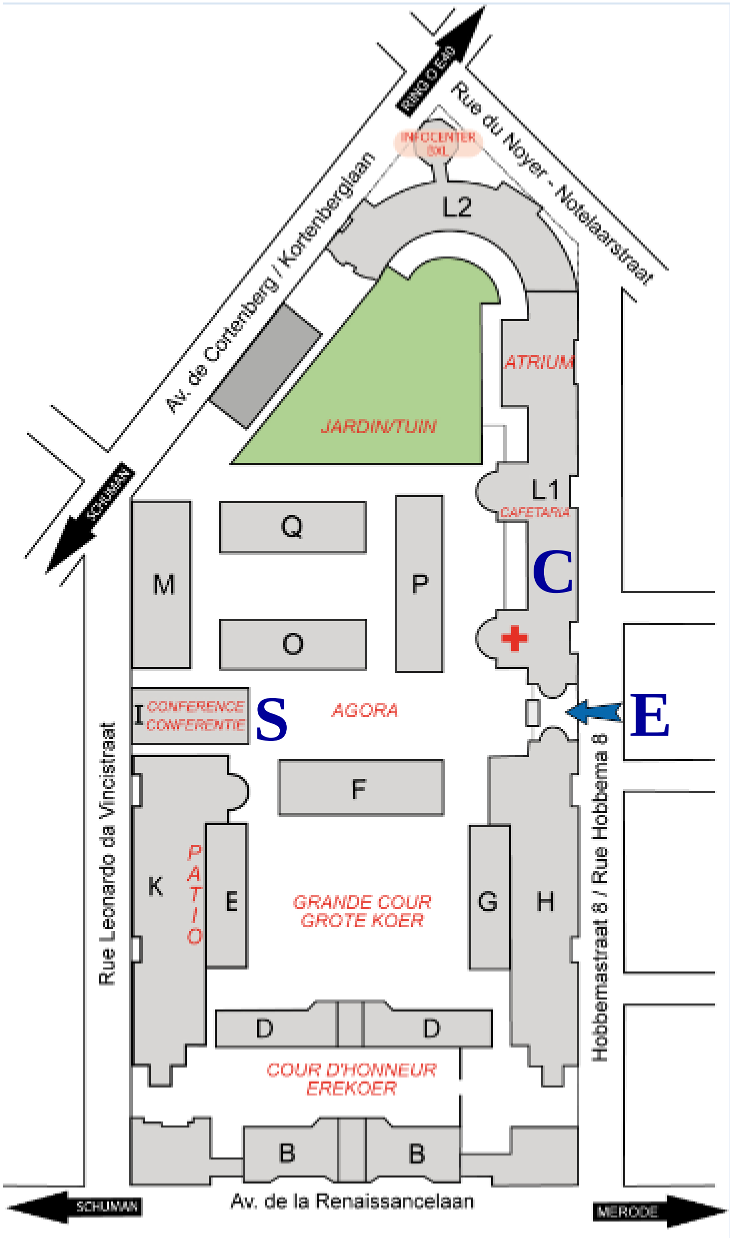
Included in the Book of Abstracts are 88 oral presentations and 23 poster presentations. The posters are on display in the special poster session area, together with 7 industrial exhibition stands. I hope you will enjoy the Symposium, learn about many new aspects in the rapidly evolving CubeSat world, meet many old friends and establish numerous useful contacts.

Jean Muylaert
Director, von Karman Institute for Fluid Dynamics
QB50 Project Coordinating Person

Organisational details

Access to the premises

The 5th European CubeSat Symposium will be held at the premises of the Ecole Royale Militaire (ERM) (Koninklijke Militaire School / Royal Military School). The address of the entrance is Rue Hobbema 8, 1000 Brussels, marked by the letter **E** on the map. ERM is very close to Parc Cinquantenaire and the European Union buildings. The closest metro stops are Schuman and Merode. The web site of the Brussels Public Transportation Services www.stib.be provides detailed information on how to access these stations. The web site of ERM is www.rma.ac.be



Upon arrival at the gate, please inform the security that you are planning to attend the 5th European CubeSat Symposium. You will then be directed to the registration desk, where your badge will be handed out. Thereafter, you should use your Symposium badge to access the ERM premises.

It is very difficult to park your car in the neighbourhood or inside the Academy. We encourage you to arrive by public transportation.

Registration

The Symposium is being held in the large Auditorium of the ERM, as indicated by the letter **S** on the map. The registration desk will be open at the entrance of the Auditorium from 08.30 to 09.45. However, late arriving participants can still register. Participants will be asked to pay a modest registration fee of **250 €** to cover the expenses for lunches and coffee breaks on three days and for drinks and snacks during the reception. If you have not paid by bank transfer or by credit card, the registration fee can be paid during the registration.

Oral presentations, proceedings

Speakers will not be allowed to use their own computer during their talk, but must transfer their presentation in PDF or PPT PowerPoint to the Symposium Secretary Cem O. Asma (asma@vki.ac.be) by email or by USB flash drive, preferably half a day before the presentation.

There will be no printed Symposium proceedings, only the abstracts will be published. Each participant will be given a Book of Abstracts upon registration. The slides of all presentations will be made available after 15 June 2013 on the Symposium website.

Posters

The size of the area available for poster presentation is 120 x 85 cm. A1 size posters can be exhibited during the Symposium. The accepted participants can bring their own posters or the posters can be printed by VKI in advance (this should be the exception). Poster mounting will be possible on 3 June 2013 from 08.30 until 11.30. Standard materials for poster mounting will be available in the poster area, where the coffee breaks and receptions will be held, marked by the letter **C** on the map. Other than the lunch and coffee breaks, a dedicated poster session is foreseen on the second day of the Symposium from 18.30 to 21.00. Poster authors are expected to be present at that time next to their posters, to be available to answer questions and have discussions with Symposium participants.

Industrial exhibits

There will be industrial exhibits by the following companies:

- Innovative Solutions in Space (ISIS) BV, Delft, Netherlands
- GomSpace, Aalborg, Denmark
- Clyde Space, Glasgow, UK
- SSBV Space & Ground Systems, Hampshire, UK
- Novanano S.A.S, Saint Didier Au Mont d'Or, France
- Bright Ascension Ltd, Scotland, UK
- Berlin Space Technologies, Berlin, Germany

The industrial exhibits will take place in the poster/coffee/reception area, marked by the letter **C** on the map.

Lunch breaks

The lunch break is between 13.00 and 14.00 every day. The participants can have lunch at the VIP-II room of the ERM, marked by the letter **C** on the map.

Coffee breaks

The times for morning and afternoon coffee breaks are indicated in the programme. Coffee breaks will take place in the poster/coffee/reception area, marked by the letter **C** on the map.

Reception

On the second day of the Symposium, from 18.30 to 21.00, a reception will take place in the poster/coffee/reception area, marked by the letter **C** on the map.

Book of Abstracts

The final version of the Book of Abstracts will be given to Symposium participants at the time of registration. An electronic version will be available for download from the Symposium web site.

Royal Military Academy
Avenue de la Renaissance 30
1000 Brussels

By underground: take line 1, leave at SCHUMAN or MERODE station

By motorway: after the Ring RO, take the E40 to BRUSSELS CENTRE

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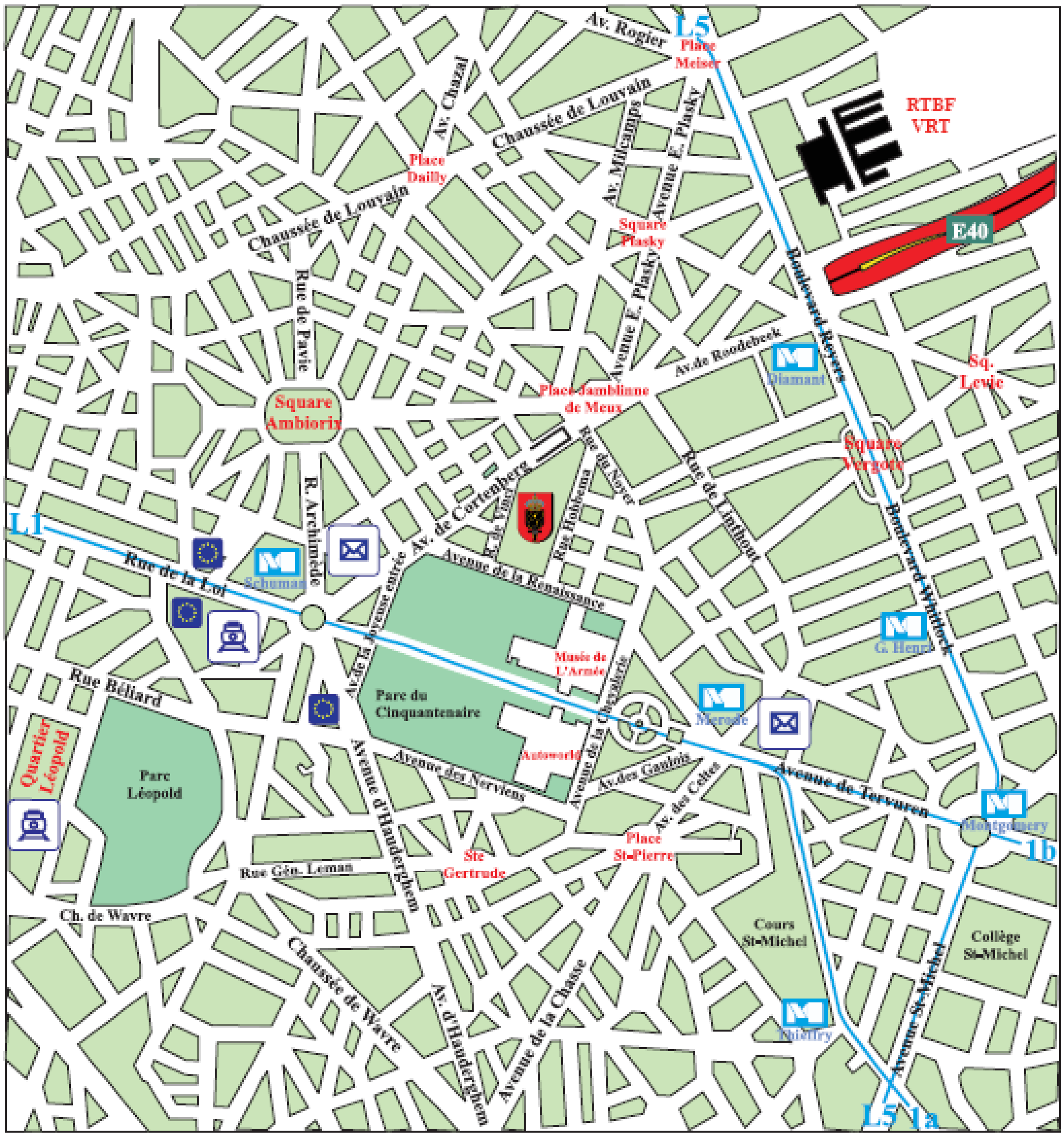
From city centre: follow the BELIARD street to the Parc du Cinquantenaire



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Programme

Monday, 3 June 2013

08.30 – 09.45 Registration, Coffee

09.45 – 10.00 Welcome and organizational details *(C.O. Asma)*

Session 1: Scientific Instruments/Sensors on CubeSats
3 June, am session: Chair: S. Dewitte

10.00 – 10.15 A novel Langmuir probe instrument for CubeSats *(S. Ranvier et al.)*

10.15 – 10.30 Bolometric oscillation sensors for microsatellite and CubeSat missions *(P. Zhu et al.)*

10.30 – 10.45 The Wind and Temperature Spectrometer (WTS) and accelerometer suite on the DANDE satellite *(S. Palo)*

10.45 – 11.00 Ex-Alta 1, a QB50 In-Orbit-Demonstration (IOD) 3U CubeSat with a novel fluxgate magnetometer *(J. Backs et al.)*

11.00 – 11.15 AaSI – Aalto-1 spectral imager development status *(K. Viherkanto et al.)*

11.15 – 11.30 The X-ray detectors on BeEagleSAT *(E. Kalemci et al.)*

11.30 – 11.45 A riometer calibration experiment on a QB50 CubeSat (RIOSAT) *(O. Koudelka et al.)*

11.45 – 12.00 NANOSAT-BR-1, mechanical analysis, ongoing and future developments *(R.Z.G. Bohrer et al.)*

12.00 – 12.15 Solar EUV sensors on board the PHOENIX CubeSat for the QB50 mission *(J. Vannitsen et al.)*

12.15 – 12.30 MinXSS: a three-axis stabilized CubeSat for conducting solar physics *(S. Palo et al.)*

12.30 – 12.45 The MOVE II mission: Detecting antiprotons in the South Atlantic Anomaly *(M. Langer et al.)*

12.45 – 14.00 Lunch break

Session 2: Technology Demonstration on CubeSats

3 June, pm session: Chair: S.R. Cunha

14.00 – 14.15 RoBisat concept, trade-off between commercial and in-house developed subsystems *(M. Balan et al.)*

14.15 – 14.30 EntrySat: a 3U CubeSat to study the atmospheric re-entry environment *(Q. Nénon et al.)*

14.30 – 14.45 GAMASAT de-orbiting control and re-entry capsule *(R. Pinho et al.)*

14.45 – 15.00 Demonstration of drag-free technology on a CubeSat *(A. Zoellner et al.)*

15.00 – 15.15 AIS reception from a CubeSat in LEO *(J.A. Larsen et al.)*

15.15 – 15.30 Software framework for measurement campaigns on a CubeSat payload *(M. Klaper et al.)*

15.30 – 15.45 Evaluation of a low-cost GNSS receiver for CubeSat missions *(C. Hollenstein et al.)*

15.45 – 16.00 Low-drag expandable solar panel to provide extra power for CubeSats *(C.S. Cordeiro et al.)*

16.00 – 16.30 Coffee break

16.30 – 16.45 Research on the on-board computer subsystem of CubeSats based on SoPC technology *(X. Yu et al.)*

16.45 – 17.00 CubeSat space protocol on an RF link *(J. Frances et al.)*

17.00 – 17.15 FPGA integrated computational module with partial reconfiguration as a CubeSat subsystem *(N. Domse et al.)*

17.15 – 17.30 Development of a robust, low-cost "CubeStar" sensor *(A. Erlank and W.H. Steyn)*

17.30 – 17.45 A simple, low-cost MPPT *(I. Fernández et al.)*

17.45 – 18.00 Validation of design methodologies for the re-entry CubeSat QARMAN *(I. Sakraker et al.)*

18.00 – 18.15 UNSW EC0 CubeSat design: Experiments in radiation tolerance critical systems, GNSS remote observation and 3-D printed satellite structures *(B. Osborne et al.)*

18.15 – 18.30 Design and tests of the coilable mast of BUAASAT *(S. Guan et al.)*

Tuesday, 4 June 2013

4 June, am sessions: Chair: W. H. Steyn

Session 3: Micropropulsion Subsystems, Formation Flying

09.00 – 09.15 From Delfi-n3Xt to the DelFFi formation flying mission: the next step of the Delfi programme *(J. Guo et al.)*

09.15 – 09.30 Miniaturized Pulsed Plasma Thrusters (µPPT) and Field Emission Electric Propulsion (FEEP) for nanosatellites *(B. Seifert and C. Scharleman)*

09.30 – 09.45 Micropropulsion system with closed-loop thrust control *(T.-A. Grönland and K. Palmer)*

Session 4: Attitude Determination and Control Subsystems (ADCS)

09.45 – 10.00 BeEagleSat attitude determination and control system *(O. Celik et al.)*

10.00 – 10.15 Evaluation of in-orbit aerodynamic stability systems for CubeSats *(T. Scholz et al.)*

10.15 – 10.30 Selection of design parameters of aerodynamically stabilized nanosatellite for thermosphere research within the QB50 Project *(I. Belokonov et al.)*

10.30 – 10.45 Low-cost star tracker with highly-efficient algorithms *(T. Delabie et al.)*

10.45 – 11.00 Rapid design and verification of miniature solar panel integrated Sun sensors *(T. Tikka et al.)*

11.00 – 11.30 Coffee break

11.30 – 11.45 Achieving high pointing knowledge throughout eclipse in QB50 application *(J. Barrington-Brown and M. Pastena)*

11.45 – 12.00 Influence of the gravitational moment on the magnetic stabilization of CubeSats in equatorial orbits *(K. Zhilisbayeva et al.)*

12.00 – 12.15 Characterization of electronic commutated brushless DC micromotors as actuators in satellite attitude control systems *(C.A. Castellanos)*

12.15 – 12.30 A test bench for attitude and orbit control systems of CubeSats *(B. Oving and A. van Kleef)*

12.30 – 12.45 3-axis set-up for testing the ADCS subsystem *(M.T. Ganesh and V. Kishore)*

Session 5: Telecommunications, Ground Stations, Ground Station Networks

12.45 – 13.00 Towards a ground station network for QB50 *(P. Beavis and R. Reinhard)*

13.00 – 14.00 Lunch break

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4 June, pm sessions: Chair: S. Palo

14.00 – 14.15 Iterative simulation of the BUSAT-1 communications segment as an element of QB50 and GENSO networks *(H. Jazebizadeh et al.)*

14.15 – 14.30 Design and implementation of a network of one picosatellite and four ground stations *(J. Paternina et al.)*

14.30 – 14.45 Optimizing data download to a cluster of networked ground stations: a model for the QB50 Project *(R.A. de Carvalho et al.)*

14.45 – 15.00 Web service for satellite tracking and prediction for the 14-BISAT Project *(L.G.L. Moura et al.)*

15.00 – 15.15 GAMANET: Networking QB50 – first results *(P. Rodrigues et al.)*

15.15 – 15.30 Optimization of ground station locations for the tracking of nanosatellites using 3D modeling techniques *(J. Nieves Chinchilla et al.)*

15.30 – 15.45 Design of an embedded module for pictures transmission for CubeSat *(C. Dromas et al.)*

15.45 – 16.00 Advanced autonomy concept for low-cost ground stations *(A. Freimann et al.)*

16.00 – 16.30 Coffee break

16.30 – 16.45 The COMM communications subsystem of the QBito CubeSat, a demonstrator for gaining hands-on experience *(M. Gallego et al.)*

Session 6: Orbital Dynamics, Lifetimes for CubeSats

16.45 – 17.00 Probabilistic assessment of the orbital lifetime of a standard QB50 CubeSat *(L. Dell'Elce and G. Kerschen)*

17.00 – 17.15 Lifetime analyses for QB50 2U CubeSats in orbit *(C. Kilic et al.)*

17.15 – 17.30 Lifetime analysis of CubeSats in the QB50 network from the perspective of mean orbital elements *(M. Li et al.)*

17.30 – 17.45 Initial conjunction risk analysis between the ISS and the QB50 network *(C. Kilic and A.R. Aslan)*

Session 7: CubeSat Networks and Constellations

17.45 – 18.00 Highly integrated QB50 antenna, power and interface system *(J. Elstak et al.)*

18.00 – 18.15 Attitude determination and control subsystem for a swarm of nanosatellites *(N. Vinogradov and I. Kudryavtsev)*

18.15 – 18.30 The NEE constellation: video satellites for elementary education *(R. Nader et al.)*

18.30 – 21.00 Poster viewing session, visit of industrial exhibits, reception

Wednesday, 5 June 2013

5 June, am sessions: Chair: A. J. Ridley

Session 7: CubeSat Networks and Constellations, continued

09.00 – 09.15 CYGNSS – a microsatellite constellation mission for measuring winds in hurricanes *(A.J. Ridley et al.)*

09.15 – 09.30 Ground stations and communication protocols for small satellite networks and constellations *(R. Pinho et al.)*

09.30 – 09.45 The QB50 Project *(J. Muylaert et al.)*

09.45 – 10.00 A CubeSat constellation for low-frequency radio astronomy *(R. Reinhard)*

10.00 – 10.15 A CubeSat constellation for micro-scale plasma physics in the magnetosphere *(R. Reinhard)*

Session 8: CubeSat Flight Experience, Lessons Learned

10.15 – 10.30 Low-resource in-situ sensors suitable for CubeSats *(D. Kataria)*

10.30 – 10.45 On-orbit performance of the Colorado Student Space Weather Experiment (CSSWE) *(S. Palo et al.)*

10.45 – 11.00 AAUSAT3 – a new satellite infrastructure *(J.F. Dalsgaard Nielsen and J.A. Larsen)*

11.00 – 11.30 Coffee break

11.30 – 11.45 Experiences and lessons learned during the launch and early orbit phase (LEOP) of AAUSAT3 *(J.F. Dalsgaard Nielsen and J.A. Larsen)*

11.45 – 12.00 Five years of successful space education and outreach in Estonia (M. Noorma et al.)

12.00 – 12.15 Lessons learned from the attitude determination and control subsystem of ESTCube-1 *(E. Kulu et al.)*

12.15 – 12.30 Improving and accelerating small missions through mission operations software *(E. Eilonen et al.)*

12.30 – 12.45 Lessons learned in the PW-Sat Project *(M. Urbanowicz et al.)*

12.45 – 13.00 Rapid development of on-board software with software components *(P. Mendham and M. McCrum)*

13.00 – 14.00 Lunch break

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5 June, pm sessions: Chair: J. Muylaert

14.00 – 14.15 Design of a flight software framework of CubeSats supporting a multi-layer operating system *(S.-H. Han et al.)*

14.15 – 14.30 QBito EPS and structure as technology demonstrators for students *(A. Laverón et al.)*

14.30 – 14.45 Nanosatellite myths versus facts *(M. Pariente)*

Session 9: Future Technologies on CubeSats

14.45 – 15.00 The NANOSAT FP7 Project – nanosatellites beyond 2013 *(M. Noorma et al.)*

15.00 – 15.15 OPS-SAT, an ESA 3U CubeSat for accelerating innovation in satellite control *(D. Evans and M. Merri)*

14.15 – 15.30 X-band downlink capability for CubeSats *(E. Peragin et al.)*

15.30 – 15.45 Satellite ID tag *(I. Vuletich et al.)*

15.45 – 16.00 Electric solar wind sail propulsion outside the magnetosphere on board a CubeSat *(K. Prants et al.)*

16.00 – 16.30 Coffee break

16.30 – 16.45 A free-return CubeSat mission to prepare the human exploration of Mars *(J. Vannitsen et al.)*

16.45 – 17.00 Alternative image compression for CubeSats *(W. Kiadtikornthaweeyot and A.R.L. Tatnall)*

17.00 – 17.15 High-resolution images obtained by 'computational imaging' *(J. Sun et al.)*

17.15 – 17.30 Phase change material for CubeSat thermal management *(J.-P. Collette and P. Rochus)*

17.30 – 17.45 Innovative low-cost thermal components for CubeSats *(A. van Kleef)*

17.45 – 18.00 PICARD, an on-board computer for future CubeSat missions *(T. Rajkowski and R. Graczyk)*

18.00 – 18.15 The OPEN prototype for educational nanosatellites *(J. Straub et al.)*

Session 10: CubeSat Deployers

18.15 – 18.30 S2S-CAM, an autonomous camera system with near real-time image delivery capability (*I. Kalnins and W. Bode)*

18.30 – 18.35 Closing remarks *(J. Muylaert)*

Session 1

Scientific Instruments/Sensors

on CubeSats

A Novel Langmuir Probe Instrument for CubeSats

S. Ranvier, P. Cardoen, J. De Keyser, D. Pieroux

Belgian Institute for Space Aeronomy, Brussels, Belgium

A novel Langmuir probe instrument that can be accommodated on a CubeSat is under development at the Belgian Institute for Space Aeronomy. This instrument includes four cylindrical probes whose electrical potential is swept in such a way that both electron temperature and electron density can be derived. In addition, since at least two probes will be out of the spacecraft's wake, differential measurements will be performed in order to increase the accuracy. The probes will be mounted on 5 cm long booms, at the extremity of 20 cm long solar panels deployed perpendicularly to the body of the spacecraft.

The sweeping Langmuir probe (SLP) instrument, together with VISION (visible and near-infrared hyper-spectral imager) and µBOS (micro-bolometer oscillation system) will form the payload of PICASSO, a 3U CubeSat of the Belgian Institute for Space Aeronomy and the Royal Observatory of Belgium. It is planned to fly on the QB50 mission in a quasi-polar orbit at about 500 km altitude, with an orbital lifetime of at least two years. The spatial sampling will be about 150 m, corresponding to one electron temperature and density data point every 20 msec.

In order to avoid spacecraft charging, which leads to erroneous measurement data, the probes will be swept with a duty cycle of less than 5%. In addition, to avoid probe surface contamination and ageing, a high voltage will be applied to the probes when necessary. The raw data will be processed on board, using a dedicated FPGA. Only the compressed parameters of interest will be sent back to the ground station via an S-band link.

Given the high inclination of the orbit, the SLP instrument will allow a global monitoring of the ionosphere. Therefore, PICASSO will enable the study of space weather phenomena such as ionosphere-plasmasphere coupling, the subauroral ionosphere and corresponding magnetospheric features, auroral structure, polar cap arcs, ionospheric dynamics via coordinated observations with EISCAT's heating radar, and turbulence in the partially ionized ionosphere.

Bolometric Oscillation Sensors for Microsatellite and CubeSat Missions

P. Zhu, O. Karatekin and M. van Ruymbeke

Royal Observatory of Belgium, Brussels, Belgium

A bolometric oscillation sensor monitors the electromagnetic radiation at the visible as well as infrared wavelengths. The information obtained by the sensor has applications in geophysics, climatology and solar physics.

The Bolometric Oscillation Sensor (BOS) has been designed and built for the PICARD mission. The objectives of the mission are to monitor the total solar irradiance (TSI), to measure the solar diameter, to measure the thermal radiation from the Earth and to study the connection between the solar activity and the Earth’s climate. The PICARD microsatellite was successfully launched on 15 June 2010 into a low-Earth orbit at 725 km altitude.

The micro-Bolometric Oscillation Sensor (µBOS) is the second generation of the BOS sensor. The general working principle is the same but there are more strict limits in terms of the power budget and volume since it will be a payload of the 3U CubeSat mission PICASSO. One of the main challenges for the design is that the sensor will not have a thermal stabilization system. Despite this fact, a large dynamic range and low noise of flux measurements are desired. In order to reach the objectives, we have tested different geometries and designs of the sensor.

In this paper we will first present design, performance and data of BOS on board the PICARD satellite. Then we will present the second-generation sensor (µBOS) designed for the PICASSO CubeSat mission. The design and properties of µBOS will be given and its predicted performance will be presented in comparison with the BOS.

The Wind and Temperature Spectrometer (WTS) and accelerometer suite on the DANDE satellite

S. Palo

Department of Aerospace Engineering Sciences, University of Colorado,
Boulder, Colorado 80309-0429, USA

The DANDE (Drag & Atmospheric Neutral Density Explorer) project aims to further the understanding of atmospheric response and drag forcing due to changes in geomagnetic activity. The lower thermosphere is of interest because of the transition in flow regimes, and from a highly eccentric orbit the satellite will be able to provide estimates of density and winds at a range of altitudes. The goal of the DANDE mission is to make measurements of thermospheric composition, temperature, wind velocity, and acceleration in both space and time. These measurements, provided by two on-board instruments, allow for a systematic approach to studying the full drag equation. The spherical spacecraft (diameter 45 cm, mass 50 kg) is spin stabilized minimizing attitude dependent drag variations and enabling ground tracking for independent validation of the drag environment through precision orbit analysis.

Atmospheric measurements of composition, temperature, and wind velocity are collected with the Wind and Temperature Spectrometer (WTS). The heritage of this design is similar in its neutral sensing function to the Winds-Ions-Neutral Composition Suite (WINCS) developed at Goddard Space Flight Center and currently scheduled to fly on the Air Force SENSE and the NSF CADRE missions. Specifically, this instrument measures horizontal (cross-track) wind angle off the boresight of the instrument aperture. Determination of atmospheric composition comes from the differences in mass resulting in separation of incoming species in the energy spectrum and integrating in time, enabling an estimate of O:N2 made over a 10 km region. Complementary data from an accelerometer suite provides knowledge of the bulk perturbing forces on the spacecraft from atmospheric forcing. The accelerometer instrument is comprised of six navigation grade accelerometer heads arranged on the facets of a hexagonal prism. The sensing mechanism takes advantage of the spacecraft spin as each accelerometer head is rotated into and out of the velocity vector and thus modulating the input drag signal which can then be filtered out for scientific measurement with a resolution of ~70 ng.

DANDE is scheduled to launch in the 3rd quarter of 2013 into a highly eccentric, near-polar, low-Earth orbit. DANDE is not the only space weather related mission on board this launch, a set of three 10 cm diameter aluminum spheres called the Polar Orbiting Passive Atmospheric Calibration Spheres (POPACS) will be deployed as well. An ad-hoc constellation of passive spheres in a similar orbit as DANDE will provide an unprecedented opportunity to demonstrate a multipoint neutral sensing mission using both active and passive satellites. Observing the drift between objects will provide an additional source of validation and cross-calibration for the DANDE on-orbit measurements.

The future opportunity to launch and operate multiple DANDE satellites simultaneously in a small 8-10 satellite constellation will provide novel measurements at different local times to study the spatial variability of the thermosphere. The impact of this spatial variability on satellite drag is currently unknown and important to quantify.

DANDE is a product of the partnership between the Colorado Space Grant Consortium and the Department of Aerospace Engineering Sciences at the University of Colorado, Boulder. This is a student designed and developed mission made possible through the Air Force Research Laboratories University Nanosatellite Program from the 5th Competition Cycle.

Ex-Alta 1, a QB50 In-Orbit-Demonstration (IOD) 3U CubeSat with a Novel Fluxgate Magnetometer

J. Backs, D. Miles, C. Robson and I. Mann

Department of Physics, University of Alberta, Edmonton, Alberta, Canada

In response to the international QB50 initiative, the AlbertaSat student team at the University of Alberta has proposed the Ex-Alta 1 satellite (Experimental Alberta Satellite #1) in the category of 3U In-Orbit-Demonstration (IOD) CubeSats. It will be a test platform for the space qualification of Alberta-designed instruments and engineering skills. Ex-Alta 1 will fly for approximately 5-8 months through the Earth's lower thermosphere/ionosphere and will carry a novel digital fluxgate magnetometer designed at the University of Alberta in addition to a standard QB50 payload.

Fluxgate magnetometers are an essential tool for solar-terrestrial research and monitoring space weather. They provide high-precision measurements of the Earth's magnetic fields, can be used to infer the currents which transport mass and energy through the magnetosphere and ionosphere, and are required to interpret all charged particle measurements. Canada has a tradition of magnetometer excellence and the University of Alberta has designed a prototype digital fluxgate magnetometer that can provide high frequency measurements up to ~3 kHz, which would previously have required the additional flight of an induction coil magnetometer. This significantly enhances the scientific capability of CubeSats, as the prototype magnetometer presents a high performance alternative to induction coil magnetometers in a single lightweight package.

The magnetometer sensor will be mounted on a boom, 75 cm to 1 m in length, with a nominal mass of 120 g. The resolution of the magnetometer is 8 pT. The sensor mass will be less than 500 g, electronics less than 150 g. The power consumption will be less than 500 mW in science mode and less than 100 mW average in attitude determination mode. The possibility of having two sensors on the boom, one outboard, one inboard, is under discussion.

The Ex-Alta 1 satellite is planned to launch in 2015 as a part of QB50. This mission will lead to the collection of scientific data for QB50 and, critically, the space verification of the prototype magnetometer and the promotion of the space industry in western Canada. Once the prototype magnetometer is space-tested, it will become a valuable tool for future space missions to study the Earth's magnetic fields.

AaSI – Aalto-1 Spectral Imager development status

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The Aalto-1 Spectral Imager (AaSI) is a miniaturized spectral imager capable of recording images at 20+ selectable wavelength bands between 500 and 900 nanometers and it will fly on the Finnish Aalto-1 student satellite. VTT has developed tunable Fabry-Pérot interferometer (FPI) technology based on either piezo or electrostatic actuation. These technologies enable extremely lightweight spectrometers and spectral imagers (< 500 g) which are suitable for small unmanned aerial vehicles and different space applications.

A spectral imager can be built by combining the tunable FPI with an RGB CMOS or CCD sensor. AaSI will have an RGB CMOS sensor consisting of 1024 x 1024 pixels which will be used in 2 x 2 binning mode. This allows the minimum ground pixel size of ca. 200 m from a 600 km orbit. In addition to this, AaSI will also include a normal colour camera with a resolution of 1910 x 1270 pixels. The images taken by this camera will be used as a georeference for the spectral images. The spectral, radiometric and spatial performance of the instrument will be tested on the Aalto-1 nanosatellite mission. As Aalto-1 will have limited downlink capacity, the amount of measured spectral bands has been reduced. However, the instrument itself can measure 60+ spectral bands, and this feature may still be tested during the mission. In-orbit spectral calibration is planned to be done by using known bright spectral features (e.g. the Sahara desert) and measuring the spectrum around strong absorption peaks (e.g. O_2 absorption at 750-760 nm). Also on-board calibration using the 500 and 900 nanometer filter edges will be possible.

The piezo-actuated FPI used in AaSI has already passed space qualification testing and the instrument has passed the critical design review. In the current design the instrument envelope is 97 x 97 x 48 mm^3 with a mass of ca. 600 g. The construction of the complete qualification model is currently under way and the flight model is expected to be completed during the autumn of 2013.

The main advantages of the AaSI concept are the small size and the spectral programmability, which provides flexibility and reduced data rate when the application is well defined. A successful space qualification and orbit demonstration will enable development of more advanced instruments based on piezo and MEMS Fabry-Pérot interferometer technologies.

The X-ray Detector on BeEagleSAT

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BeEagleSAT is a 2U CubeSat to be launched within the EU FP7 project QB50. It is being designed by the Istanbul Technical University and Turkish Air Force Academy. Sabanci University will provide a CdZnTe based semiconductor X-ray detector and its associated readout electronics as a secondary payload. The detector will utilize cross strip geometry to test the imaging capabilities of the detector system and demonstrate the space readiness of the associated electronics.

The readout will be established by a 36 channel ASIC, an ADC and a microcontroller. The system will have its own battery and will be turned on intermittently due to power and telemetry constraints. It will characterize the hard X-ray background in the range 20-200 keV as a function of altitude in low-Earth orbit.

Some of the challenges for the payload include designing low-noise power circuits for the ASIC including high voltage (300 V), minimizing power used by the ASIC and the associated electronics, optimization of the data taking due to telemetry constraints, attachment of the 3 mm thick, 20 mm x 20 mm CdZnTe crystal to the board and maintaining electrical contacts on the cathode side.

A Riometer Calibration Experiment on a QB50 CubeSat (RIOSAT)

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A riometer (relative ionospheric opacity meter) is a ground-based instrument used to quantify the amount of absorption of radio waves from natural radio sources predominantly in the Milky Way Galaxy by the ionosphere. The extraterrestrial radio sources have to be highly stable, meaning that their radio power must be constant in time. The Sun and Jupiter are the strongest radio sources in the Solar System but, because their radio emissions are highly variable, these sources are unsuitable for riometer measurements.

The difference between a 'quiet-day' curve, obtained at times of negligible ionospheric absorption, and the riometer signal, obtained at a time of increased ionospheric absorption, is an indicator of additional (and sporadic) ionisation of the ionosphere and is measured in dB. The electrons in the D layer of the ionosphere (60-90 km) are responsible for the absorption of the radio waves. The layer shrinks substantially after sunset, therefore, absorption is small at night and largest at about midday. The ionospheric properties depend on solar activity. During solar proton events, ionisation in the D layer can reach unusually high levels at high latitudes. Such rare events are known as Polar Cap Absorption (PCA) events, because the increased ionisation significantly enhances the absorption of radio signals passing through the region. In fact, absorption levels can increase by many tens of dB during intense events, which is enough to absorb most (if not all) transpolar HF radio signal transmissions.

RIOSAT is a standard atmospheric 2U CubeSat accommodating the QB50 Sensor Set 3, consisting of the four-needle Langmuir probe and laser reflectors. As the Institute's own experiment, RIOSAT will also carry out a riometer measurement 'in reverse'. Instead of using galactic radio sources from above, RIOSAT will use radio signals from below, emitted by HF transmitters located in the northern and southern polar regions. Just like the extraterrestrial radio sources, the emitted radio power from the sources on the ground has to be highly stable. Therefore, normal radio stations are not suitable. Up to 10 highly stable, low-cost transmitters will be set up on the ground for this purpose. They will be set up near existing riometer stations, do not need to be attended by operators and will remain active as long as RIOSAT is in orbit. During each pass of RIOSAT over a transmitter ground station the transmitter will transmit sequentially at four different frequencies(7, 14, 21 and 28 MHz), typically at each frequency for 0.5 to 1 minute, depending on the total duration of the pass. In this way, about 10,000 ionospheric soundings are possible during the QB50 operational phase.

For synoptic studies of the ionosphere the participating ground-based riometers have to be calibrated in the same fashion. Up to now, this has not been possible. However, with RIOSAT this calibration can be achieved for the first time. As RIOSAT flies over a riometer ground station located adjacent to a RIOSAT transmitter both the four receivers on board RIOSAT and the ground-based riometer determine the ionospheric absorption at the same time and location, allowing a comparison and thereby calibration of the data. RIOSAT will achieve this calibration numerous times for all ground-based riometers which are located close to one of the RIOSAT ground-based transmitters. RIOSAT will be the first space-borne riometer. A space-based receiver has the advantage of being able to measure the ionospheric properties on a global scale and not only from a few ground stations with their limited coverage. The measurements by the space-based riometer and the ground-based riometers will be mutually complementary.

NANOSATC-BR1, Mechanical Analysis, Ongoing and Future Developments

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The Brazilian NANOSATC-BR CubeSat Development Program is based on the worldwide CubeSat concept with emphasis on capacity building of the new generation of aerospace professionals through every step of a real space project, from planning to development, implementation and operation.

As a first project, NANOSATC-BR1 will monitor the space weather and atmospheric anomalies over the Brazilian territory, such as the geomagnetic field disturbances and their effects on the region known as the South Atlantic Magnetic Anomaly (SAMA). Aiming for a quick development, the first CubeSat as well as the ground station were purchased from Innovative Solutions In Space (ISIS). They are used as model for reverse engineering and training of students involved in the Project.

This paper will present the current stage of the NANOSATC-BR1 satellite, the scheme and the students' involvement in the project, focusing on studies and analysis performed on the mechanical platform. Analysis results will be presented and discussed, based on the Indian Polar Satellite Launch Vehicle (PSLV) and mechanical project requirements.

In conclusion, a summary of the present studies and proposals for a new 1U CubeSat platform is presented, developed to support the subsystems of future academic space projects, as well as the present developments of the NANOSATC-BR2, the second nanosatellite project.

Solar EUV Sensors on board the PHOENIX CubeSat for the QB50 Mission

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It is now well known that solar EUV irradiances are responsible for creating the terrestrial ionosphere and for heating the thermosphere. An accurate knowledge of this flux is, therefore, necessary for aeronomical studies of the upper atmosphere.

National Cheng Kung University has proposed the development of the PHOENIX CubeSat in the QB50 program. The 2U PHOENIX CubeSat is planned to carry the science Sensor Set 1, which includes the Ion and Neutral Mass Spectrometer (INMS), corner cube laser retroreflectors, as well as thermistors. In order to increase the science return of the mission a second payload has been proposed for PHOENIX, consisting of two solar EUV sensors.

Integrated solar EUV intensity is estimated by monitoring the secondary electrons emitted from the metal surface as a current which flows into ambient plasma. The instrument consists of a current amplifier and a metal electrode. Most of the time, the satellite is negative with respect to the ambient plasma and, therefore, the electrode, which is used as a sensor, is connected through an amplifier to the satellite frame, or the electrode might be slightly biased to negative with respect to the satellite frame. The proposed payload would then consist of two solar EUV sensors (electrodes), one located on one of the side panels of the satellite, the other next to the science unit. When a sensor faces the Sun the solar EUV flux is measured, when a sensor faces the Earth the EUV flux due to the Earth albedo is measured.

The manufacturing cost of these devices would be very low and it would be fast to produce. This payload could be manufactured and tested locally by using a Deuterium lamp as a EUV source in the space operation chamber at the National Cheng Kung University. The low mass, low cost, low data rate and low power consumption of the EUV sensors in view of the significant science return make them a perfect payload for a CubeSat taking part in the QB50 Mission.

MinXSS: A Three-Axis Stabilized CubeSat for Conducting Solar Physics

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The Miniature X-ray Solar Spectrometer (MinXSS) is a 3U CubeSat designed to better understand the energy distribution of solar flare soft X-ray (SXR) emissions and its impact on the Earth's ionosphere, thermosphere, and mesosphere (ITM). The peak solar energy in the SXR is expected to be emitted near 2 nm, yet we have limited spectral measurements near that wavelength to verify this expectation. Energy from SXR radiation is deposited mostly in the ionospheric E-region, from ~80 to ~150 km, but the precise altitude is strongly dependent on the SXR spectrum because of the steep slope and structure of the photoionization cross sections of atmospheric gases in this wavelength range. Despite many decades of solar SXR observations, almost all have been broadband measurements with insufficient spectral resolution to fully understand the varying contributions of emission lines amongst the underlying thermal and non-thermal continua. MinXSS will improve the understanding of how highly variable solar X-rays affect the ITM, advance our knowledge of flare energetics in the SXR, and provide new spectral observations of the solar SXR near the maximum of solar cycle 24.

The MinXSS bus is a 3-axis-controlled CubeSat to observe the solar SXR spectrum between 0.04 and 3 nm. The x-ray spectrometer on MinXSS has a spectral resolution that is almost constant in energy, better than 0.15 keV FWHM, corresponding to a wavelength resolution of 0.0002 nm FWHM at 0.04 nm up to 1 nm FWHM at 3 nm (note: a 1 nm photon has an energy of 1.24 keV). The MinXSS science measurements will be achieved using the commercially available X123 advanced X-ray spectrometer which has an active area of 25 mm^2, an effective Si thickness of 0.5 mm, an 8-µm-thick Be filter on the detector vacuum housing, an active 2 stage thermoelectric cooler (TEC) on the detector, and sophisticated multichannel analyzer (MCA) detector electronics. This commercially available handheld x-ray spectrometer was recently flown on a sounding rocket and provided the ability to operate in space.

Key to achieving our science goals is accurate pointing control and knowledge. With the wide field of view of the X123 spectrometer (±4°), the pointing requirements for MinXSS are only 2° (3-sigma) accuracy and 0.05° (3-sigma) knowledge. To meet these requirements we are using the new fleXible ADCS Cubesat Technology (XACT) from Blue Canyon Technologies (BCT). This ADCS utilizes a nano star camera to attain pointing knowledge to better than 0.02° in all three axes. Micro-reaction wheels and magnetorquers provide the pointing control. This system operates at nominal power draw of 0.5 W, has a mass of 0.7 kg and fits into a 0.5U volume.

In this talk we will describe the science goals of the project, give a mission overview, and discuss the current bus design with a specific focus on the attitude control system.

The MOVE II Mission: Detecting Antiprotons in the South Atlantic Anomaly

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MOVE II is a 2U CubeSat currently under development at Technische Universität München (TUM). The main objective of the MOVE II mission is to measure the flux of magnetically trapped antiprotons with kinetic energies below 80 MeV in the South Atlantic Anomaly (SAA).

Several theoretical models have been published in the last 20 years describing the creation and trapping mechanisms for antiprotons and the resulting particle fluxes. The same models used to describe the formation of the Van Allen radiation belts can be applied to describe the accumulation of antiprotons in a belt-like structure, often referred to as an antiproton radiation belt. In 2011, the first detection of trapped antiprotons was announced by the PAMELA collaboration. The flux of antiprotons measured by PAMELA in the energy range from 80 MeV to 190 GeV deviates from the theoretical models by a factor of 10 to 100. MOVE II will measure the flux of antiprotons with kinetic energies below 80 MeV, an energy range for which no data is available so far. The experimental data will help to better understand the production and trapping processes of the antiproton belt formation. Therefore, the main scientific goal of the MOVE II mission is to gather enough data to improve the model of antiproton creation and trapping in the Earth's magnetic field.

The main instrument of the mission is a particle detector based on scintillating fibers with a silicon photomultiplier (SiPM) readout, which is being developed at the E18 Physics Department (TUM). The detector concept is based on the annihilation of antiprotons stopping in the detector material and the detection of particles created in this process. The instrument occupies half the volume of the 2U CubeSat, specifically designed for the mission at the Institute of Astronautics (TUM), but derived from our first CubeSat mission, the First-MOVE (Munich Orbital Verification Experiment). Accordingly, as many subsystems as possible of the 1U First-MOVE satellite will be reused or adapted. The MOVE II mission's target altitude is approximately 600 - 800 km, ideally with an inclination of 90° and a mission duration of at least 1 year.

The main design drivers for the satellite are the high power and data transmission demands as well as the high radiation environment inside the SAA. The CubeSat form factor results in a detector design that is cube shaped, contains 900 detection channels and is slightly smaller than 1U. A preliminary design of the detector has been modeled using Geant4. The next major step in MOVE II is the construction of a detector prototype and the demonstration of the detection principle at different facilities. The preliminary design review for the entire satellite system is scheduled for early 2014.

Session 2

Technology Demonstration on CubeSats

RoBisat Concept
Trade-off between commercial and in-house developed subsystems

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RoBiSAT is a project proposed by a consortium formed by the Institute of Space Science, Romania and the Romanian Space Agency Research Center in the context of QB50. In addition to the QB50 mission objectives, the project's goal is to test bi-directional inter-satellite communications as a prerequisite for developing future formation flying missions. In order to achieve this goal, two identical satellites are going to be designed, built and operated as part of the QB50 mission. The satellites will be designed to meet the overall QB50 system requirements and, furthermore, the exact position of each satellite shall be precisely known in order to evaluate the inter-unit communications as a function of distance and transmitting power. To speed up the development, the flight bus will consist of two identical 2U CubeSats built using both existing commercial and in-house developed subsystems. The payload will include one of the standard QB50 science sensor sets and the inter-satellite communications unit.

Specifically, this paper presents the RoBiSat satellite platform development and the trade-offs made by our team in COTS component selections. Moreover, the paper focuses on the description of the power supply unit as a relevant in-house developed subsystem and describes the specific customizations made in order to reach the QB 50 mission requirements.

EntrySat: a 3U CubeSat to Study the Atmospheric Re-Entry Environment

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QB50 is a network of 50 CubeSats planned for launch in 2015 into a near-circular, Sun-synchronous orbit at 380-400 km altitude, just below the orbit of the ISS. This project was initiated in 2009 by the von Karman Institute for Fluid Dynamics in Brussels, Belgium to fulfill scientific, technological and educational purposes. ISAE's 3U EntrySat student satellite has been proposed as one of the 10 QB50 In-Orbit-Demonstration (IOD) CubeSats.

As in-orbit collisions and satellite orbital decay have demonstrated that orbital debris represents a potential threat to access to space as well as a threat to ground safety, the EntrySat experiment, with CNES and ONERA as partners, consists of inserting the EntrySat satellite into low-Earth orbit which is similar, in principle, to secondary debris typically issued from launch vehicles or satellites. A science module operating during the re-entry phase will be able to perform in-situ measurements of the CubeSat environment as well as integrity up to its destruction.

The scientific objectives have been defined in collaboration with ONERA and are the following: to refine the atmospheric modeling between 120 and 380 km and the aerodynamic coefficients modeling. Aerodynamic forces and associated kinematics (position, attitude motions) should be available and EntrySat will perform these measurements during the orbit decay phase and the destruction phase.

As a result of the scientific goals of EntrySat, the payload includes an Inertial Measurement Unit (IMU) with magnetometers, gyroscopes and gyrometers to determine the Euler angles and their derivatives. A GPS chip is integrated in the satellite to measure the position and the velocity of EntrySat. Six washer type-k thermocouples are in the center of each of the six faces of the CubeSat to give an access to the external temperature. The thermocouple position is crucial to avoid side effects. The understanding of the drag force during the mission is also a scientific goal and six piezoelectric force sensors are, therefore, used in addition to accelerometers. Six heat flux sensors complete the in-situ measurements.

For the ADCS, the attitude control will be performed using the interaction between coils and the Earth electromagnetic field. This is accomplished by using a PID controller. The settling time to obtain a misalignment error of less than 3° is around 8 orbits.

GAMASAT De-orbiting Control and Re-Entry Capsule

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GAMASAT is a multi-partner and multidisciplinary project from the University of Porto and Tekever Space. It is a 3U In-Orbit Demonstration (IOD) CubeSat planned for launch as part of the QB50 Project in 2015. It will carry one of the three sets of standard QB50 science sensors and, in addition, two experiments.

It will integrate the GAMANET experiment to address the use of Software-Defined Radio (SDR) technology performing multiple communications related tasks like establishing and exploiting an ad-hoc network with satellite-to-satellite and satellite-to-ground links, providing larger data volume throughput, reception of GPS signals and attitude determination using radio waves. It will also carry the Q-RED experiment, in order to release a re-entry capsule following a controlled de-orbiting phase. This experiment focuses on the development of the structure of a unique miniaturized re-entry capsule and, also, the control algorithm for GAMASAT's re-entry.

A drag coefficient study was already carried out and presented to the CubeSat community before. Following this study, a control algorithm for de-orbiting will be presented. This algorithm is based on attitude control using reaction wheels to change the exposed area to the apparent wind. This algorithm operates using periodic feedback from navigation data retrieved from the GPS receiver on board, in order to adjust the re-entry trajectory to a suitable landing area towards a feasible recovery.

A successful re-entry would not be possible without the right capsule layout. This presentation addresses a capsule layout, along with its set of materials and discusses its dynamic stability and thermal protection of its payload: a SDR radio transmitter, a miniature GPS receiver, batteries, sensors and a passive dumping actuator.

Demonstration of Drag-Free Technology on a CubeSat

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A drag-free satellite flies in a purely geodesic orbit as all other forces on it are canceled out. This can be achieved by shielding a test mass inside the satellite against all forces but gravity. A sensor then measures the relative displacement between the satellite and the test mass and a control system commands thrusters to keep the satellite centered around the test mass at all times. This way external disturbances like atmospheric drag or solar radiation pressure are canceled out. The drag-free technology package, also called a gravitational reference sensor (GRS), has to be designed carefully in order to minimize internal disturbance forces that could affect the test mass such as electrostatic or magnetic forces.

The Modular Gravitational Reference Sensor (MGRS) which is under development at Stanford since 2004 is built around a spherical test mass. The relative displacement between the test mass and the satellite is measured optically with the Differential Optical Shadow Sensor (DOSS). The eight light beams of the DOSS are arranged such that the test mass blocks half of each beam in its nominal position. Any movement of the test mass leads to movements of its shadow on the photodetectors.

The DOSS CubeSat is a technology demonstration for a future drag-free CubeSat mission. The main mission objective is to demonstrate a sensitivity of 1 nm at 1 mHz. In order to achieve the requirements for low-frequency noise and lock-in detection an amplification is used. To meet the space and power constraints of a CubeSat, the lock-in algorithm is implemented digitally on a low-power digital signal processor (DSP) which acts as the main payload processor. The second mission objective is to test drag-free control algorithms with an attitude determination and control system.

This mission was recently selected for the NASA ElaNa (Educational Launch of Nanosatellites) program. The present status of the project, including recent DOSS test results, will be discussed.

AIS reception from a CubeSat in LEO

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The primary payloads on board the AAUSAT3 satellite are two different AIS receivers, one is a traditional hardware-based receiver, the other one is a software-defined radio receiver.

The hardware-based receiver has been developed around an ADF-7020 transceiver, with an appropriate LNA in front. The SDR-based receiver is developed around the similar ADF-7021, which in addition to the bit-stream output also features an output of the 200 kHz I/Q IF signal. This analogue signal is in turn sampled at around 750 kHz and then processed by a DSP.

The 1U AAUSAT3 CubeSat was launched on 25 February 2013 into a low-Earth orbit with a semi-major axis of 7156 km, i.e. 800 km altitude, near circular, dusk-dawn Sun-synchronous orbit. From this orbit the AIS antenna system, which consists of a dipole antenna, has a foot print diameter of approximately 6000 km. During the first pass over the primary ground station at Aalborg University, basic telemetry and the first few AIS messages were downloaded. During the first 14 days of the mission, the two receivers managed to detect more than 100,000 different AIS messages from ships all around the world, and more than 35,000 of these messages have been successfully downlinked to the AAU ground station for further processing.

In this paper we will explain how the two different AIS receivers are working, provide an analysis of the capabilities of the receivers in orbit, and will present some of the preliminary performance metrics which have been found for the two receivers.

Software framework for measurement campaigns on a CubeSat payload

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The complexity of the measurement campaign requires a novel software framework which enables the user to flexibly configure the scientific experiment whilst the CubeSat is in space. We propose a new software framework with a low footprint regarding memory usage, energy consumption and communication bandwidth. Depending on results during the mission, late entry change of measurement procedures is possible without updating the complete payload software to reduce the required upstream data amount. A task-specific application programming language will be presented, which is adaptable to similar payloads. By changing the measurement procedures in-flight, it is possible to adapt to new measurement procedures and different post-processing processes during the mission and also just before the re-entry into the atmosphere. The set of selected key parameters can be changed on a per orbit basis.

In addition, the software framework covers reliability and security issues in space with a redundant boot loader, an external watchdog, a logging mechanism to track failures and data integrity checks of all messages that are exchanged between subsystems. The boot loader, for example, has the ability to safely load a new software component onto the payload board. In case of software failures due to transmission errors or corrupt code, the boot loader stores backups of the current and the previous software, which enables switching between different versions whilst the CubeSat is running.

The main objective of the CubETH mission is to verify algorithms for high-precision measurements of spacecraft position and attitude using COTS GNSS sensors. We plan to use u-blox receivers in our new satellite, which will be based on the successful SwissCube design. The control hardware and software of the GNSS receivers shall provide a flexible infrastructure for various scientific experiments.

This project is a cooperation between the Geodesy and Geodynamics Lab of ETHZ , the Swiss Space Center (SSC) at EPFL and several universities of Applied Sciences. It is also supported by Swiss companies. The Department of Computer Science and the Department of Electrical Engineering of the Lucerne University of Applied Sciences and Arts are responsible for the basic payload infrastructure.

Evaluation of a Low-Cost GNSS Receiver for CubeSat Missions

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CubETH is a new cooperative Swiss CubeSat project of ETH Zurich, the Swiss Space Center (SSC), several universities of Applied Sciences, and Swiss companies. CubETH will be equipped with several u-blox GNSS (Global Navigation Satellite Systems) receivers used for different scientific tasks, such as precise orbit determination and satellite attitude determination. u-blox GNSS receivers are low-cost, single-frequency COTS receivers for embedded solutions, characterized by good performance and very small size, mass, and power consumption and are, therefore, predestined for CubeSat missions. However, they are not space-qualified. Therefore, in the first phase of the project, numerous tests have been performed in order to study the behaviour of the receivers in the intended space environment and to evaluate their usability for space applications.

The tests performed up to now include radiation, temperature, power consumption, rotation, attitude determination and GNSS simulator tests. In this paper we describe the test setups and procedures and present first results and conclusions drawn from these test activities. The radiation tests showed, apart from the type and frequency of effects that had to be expected, a generally good recovering capability and a remarkable autonomous error detection performance of the receivers. In the temperature tests – apart from physical resistance – we were mainly interested in the behaviour of the internal clock under extreme temperatures and temperature changes and its effects on the measuring performance of the receiver. The main goals of the power consumption tests were to obtain detailed performance figures and to establish optimum receiver configuration and operation scenarios for minimised power consumption. Attitude determination, rotation and GNSS simulator tests revealed valuable information about the receiver's performance in tracking and measuring GNSS under space conditions and its impact on the scientific tasks.

Low-Drag Expandable Solar Panel to provide Extra Power for CubeSats

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The proposed paper presents the design of an expandable solar panel fixed in the middle of the rear face of a CubeSat and in the longitudinal direction of flight with the objective to provide extra power without increasing the drag. This would be ideal for CubeSats in very low-Earth orbits, like those in the QB50 mission. Due to be expandable, it is split into segments that are connected by hinges. The first segment, which is connected directly to the satellite, has one solar cell on each side and its length is half of the rear face of the satellite. The other segments have the length of the rear face of the satellite, which have two solar cells on each side.

The hinges have springs and restrictions so that the solar panel can unfold automatically. Each segment aligns at an angle of 180º to each other, and all of them are perpendicular to the rear face of the satellite. This unfolding should occur after detumbling, so that the panel will not increase the moment of inertia. The unfolding will begin when the synthetic wire, that holds the panel folded, is cut by the heating resistor attached to the wire.

Research on the On-Board Computer Subsystem of CubeSats Based on SoPC Technology

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Compared with larger satellites, CubeSats have a lower reliability since a large number of commercial devices are used for the On-Board Computer (OBC) subsystem design. In particular, the radiation tolerance of CubeSats to penetrating high-energy charged particles in the space environment is very poor. Once affected by radiation, Single Event Upsets (SEU) and Single Event Latch-up (SEL) errors of the OBC could happen. Sometimes, the result will be terrible and the satellite might be lost. Due to constraints of volume, mass and cost, improving the reliability of electronic components in CubeSats will be very difficult if the traditional method of system design is used.

To solve this problem, the team of Northwestern Polytechnical University have used the SoPC (System on a Programmable Chip) technology and carried out the OBC design based on commercial FPGA. In contrast with a conventional OBC system which adopts a single-chip microcomputer or digital signal processor as the main data handling system, this design has the advantages of high integration, small volume, low power consumption, and the capability to realize cross-platform applications. As for the resistance to space radiation, the chip comes with anti-SEU technology internally and a system-level backup hot redundancy. In comparison with the previous schemes, anti-radiation ability and reliability of the system are increased dramatically.

CubeSat Space Protocol on an RF Link

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NTNU is currently developing the NUTS (NTNU Test Satellite) CubeSat, which is mainly envisioned as an educational satellite where most tasks are performed by students, supported by university staff.

As a peculiarity this CubeSat, unlike many others, is not based on the PC104 Standard. It is, instead, developed around a backplane approach, similar to a motherboard on a desktop computer. This novel approach left us without the possibility to use readily available commercial modules for CubeSats and also with the responsibility to design an ad-hoc solution for power distribution and on-board communication. CubeSat Space Protocol on an I2C-bus was decided as the solution for the main communication bus.

Although for this given satellite the payload will be an IR Camera, the main idea is to develop a reusable platform for a variety of payloads. Thus, the exploration of new and novel technologies to be used in such platforms is also a goal. Specifically studying the viability of using an intra-satellite RF link is a specific area that NUTS is keen on exploring. Therefore, a communication bus on radio is being developed.

There are some advantages to the use of a wireless intra-satellite bus including: lower costs (both economic and in mass) and the possibility to have several transmissions in parallel. The latter could be attained by the use of virtual channels (or similar solutions) that most vendors provide on their radio kits. A proper exploitation of such features would significantly increase throughput while not requiring additional hardware.

The RF link would only be the physical layer, as it is intended to still use CSP on top of it. By keeping CSP an easier portability insured to those CubeSats that already rely on CSP. COTS radio modules are being used on the proof-of-concept implementation. This should also help for an easier deployment of this communications approach on future satellites, since components are readily available. Those satellites that are equipped with both wired and wireless busses for communication, such as NUTS, could use one as a fall back solution should the other fail. Since most of the communication stack would remain untouched the transitions between wired and wireless busses should be seamless.

The implementation is kept as hardware-independent as possible, thus deploying it on other satellites should be relatively effortless.

FPGA Integrated Computational Module with Partial Reconfiguration as a CubeSat Subsystem

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Requisite of automation, high computational capabilities and flexibility to upgrade on the fly with least human intervention are the latest trends in the space technology in this era. FPGA technology makes these facilities feasible and partial reconfiguration on these platforms makes it practical to accomplish these necessities. Amending this technology and integrating it as a subsystem pertaining to the CubeSat specifications, leads to new avenues of research, test, verification and enormous amount of possible applications.

Subsystems are modular approach to share the functionalities, improve the productivity and add credit to the main system. Enabling the subsystem with the advanced technology as reconfiguration and improving its computational capabilities contributes to the overall system augmentation and long-term productivity of the complete system.

Realization of several applications which have been suspended due to the unavailability of high computation speed, data processing can now be ventured using the developed subsystem. Partial reconfiguration technology integrated in the subsystem ensures relocation and reuse of the system resources to perceptively accommodate, several processes to run independently, catering the achievement of several application project objectives simultaneously.

Revising the subsystem to incorporate the CubeSat specifications such as physical dimensions, mass, power consumption, etc. makes it possible to use this technology to put to real test in a space environment with affordable cost, accomplishing enormous results to several researches in this field of technology. This will open several research possibilities in the fields of reconfigurable technology and space technology and conceivable application implementations.

Development of a Robust, Low-Cost "CubeStar" Sensor

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Magnetometers, Sun and horizon sensors, as well as magetorquers and reaction wheels, have all been miniaturised and successfully used on board CubeSats. These miniaturised components allow a CubeSat to be fully 3-axis stabilised, which is essential for many Earth observation, communication and science applications. However, even the current best CubeSat attitude control system has limitations. The pointing accuracy of the CubeSat is limited by the resolution of the Sun/horizon sensor to about 0.1º in daylight. The situation is much worse in eclipse, where the ADCS has to rely on magnetometer measurements, typically limiting pointing accuracy to about 2 - 5º.

The solution to this inadequacy is to include a star tracker in the ADCS. Unfortunately, while star trackers have been getting progressively smaller and more energy efficient, there is (at the time of writing) no CubeSat compatible star tracker that has been successfully flown in space. A star tracker is a complex instrument which typically requires a team of people and several years to develop. Fortunately, Stellenbosch University's Electronic Systems Laboratory has already developed several miniature satellite components. These include Sun and horizon sensors and an ARM-based on-board computer for CubeSats, as well as star trackers for the SUNSAT and FEDSAT microsatellites. The purpose of this paper is to describe how the lessons learned and subsystems developed for these products are allowing the rapid development of a CubeSat star tracker.

The star tracker being developed has a FOV of 50x26º and a limiting magnitude of 3.8. The very wide field of view allows a much smaller star catalogue to be stored and allows very fast catalogue searches. The star tracker can perform either a lost-in-space calculation, which requires searching through the whole catalogue, or an assisted match, which performs a search on a reduced catalogue based on a given rough attitude estimate. Either match can be performed faster than 1 Hz on a 48 MHz ARM processor. The matching algorithm is a modified version of the Geometric Voting Algorithm. Either individual star vectors or an inertial quaternion can be output to enable attitude determination or interplanetary navigation. The performance of the algorithm has been tested in MATLAB on simulated star images from all parts of the sky. The lost-in-space algorithm successfully matched at least three stars in 93% of the images, and the assisted match algorithm matched 98.5% of the images.

A completed engineering model has been tested on real and simulated stars. The hardware is composed of three small PCBs, each measuring 45x33 mm, stacked behind one another. The test results prove that an accuracy of better than 0.03º in bore sight pointing can be achieved on real sky images. The final hardware will consume less than 0.3 W, weigh under 100 g and be small enough that two fully contained star trackers will fit well within 0.5U volume. A fully functional CubeSat-compatible star tracker will be ready for flight by the end of 2013.

A Simple, Low-Cost MPPT

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A control technique for Maximum Power Point Tracking (MPPT) of a solar cell is presented. The aim is to develop a whole analog modular MPPT system independent from a microcontroller. Its modularity and simplicity might be an advantage compared to other MPPT systems because redundancy could be achieved with a lower number of components. This fact could reduce the failure rate and hence increase the integrity of the Electrical Power Subsystem (EPS). Following the QB50 spirit, the main ideas that have inspired the design are cost reduction, use of COTS and simplicity.

The tracking technique is based on the different behavior that increasing and decreasing signals manifest after a specific signal processing. One of the important differences from other systems is that it is only necessary to measure the current that the cell gives to the batteries to track the MPP and, hence, there is no need for an analog multiplier.

The design can be easily adjusted for obtaining a rapid response; however the faster the response, the lower the precision achieved in the determination of the MPP. Thus, a tradeoff must be investigated during the design. In any case, the obtained system requires less components and size, is independent from the initial state and can perform well even facing strong perturbations. Simulations using LtSpice and Matlab Simulink are presented in order to show how the ripple, and hence the precision, is coupled with the response time to external perturbations. The simulations have helped to make final adjustments of the parameters and to establish the performance of the system in different situations. Different results are presented and discussed.

Validation of Design Methodologies for the Re-Entry CubeSat QARMAN

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Spacecraft returning back to Earth experience a very harsh environment during the encounter with the particles of the atmosphere. One of the major issues of the atmospheric re-entry is the extreme aerodynamic heating and the exothermic chemical reactions due to the gas-surface interaction at hypersonic free stream velocities. The Thermal Protection System (TPS) design is a challenging process since the high temperature and chemically reacting hypersonic flight regime cannot be fully duplicated in ground facilities. The design methodologies, experimental and numerical, have to be validated by real flight data. However, such missions are rarely launched due to high costs.

As part of the QB50 Project, QARMAN (QubeSat for Aerothermodynamic Research and Measurements on AblatioN) is a 3U CubeSat that will perform an experiment on Earth atmospheric re-entry. Overall, this challenging mission targets to demonstrate the use of nano- and picosatellite technology to atmospheric re-entry research by providing successful real flight data at highly affordable costs when compared to other missions of space agencies that cost hundreds of million Euros.

QARMAN has a low-density ablative thermal protection material at the nose and will perform an atmospheric re-entry, representative of real missions, with approximately 7.7 km/s at 120 km altitude with a peak cold-wall heat flux of 2.0 to 2.5 MW/m^2. The TPS sizing methodology is to be validated by the measurements that will be performed during the flight. The objectives of the in-flight experiments are

- to retrieve real flight data on ablator efficiency (temperature, pressure, recession),
- species radiation in the aero thermochemical environment,
- temperature/pressure/skin friction measurements for transition and thermal insulation efficiency on the side panels,
- pressure/accelerometer/gyroscope measurements for stability and trajectory rebuilding.

Proper velocity and attitude conditions before re-entry at 120 km will be achieved by the other important payload, called AeroSDS (Aerodynamic Stability and De-Orbiting System). Due to the high disturbance torques in lower altitudes, QARMAN cannot rely on magnetorquers or reaction wheels which would exceed the available mass, power and volume budget of the constraining CubeSat platform. Since the aerodynamic stabilization moments scale with the disturbances caused by increasing density, the approach provides a reliable and passive system without any needs of external control.

UNSW EC0 CubeSat Design: Experiments in Radiation Tolerance Critical Systems, GNSS Remote Observation and 3-D Printed Satellite Structures

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The University of New South Wales (UNSW) is participating in the QB50 Project as a satellite builder/operator of the CubeSat UNSW EC0 (UNSW Educational CubeSat Zero). UNSW EC0 will be a 2U CubeSat that will carry the standard science sensor set 1 (INMS) as well as incorporating four additional payloads.

There are three payload boards

1. Namuru - a new space GPS board developed at UNSW that will carry out positioning functions as well as operating as a GNSS remote observation platform,
2. seL4 - a radiation tolerant systems computer board running a robust microkernel operating system developed by NICTA and
3. RUSH - An FPGA based systems computer board that will demonstrate and validate new approaches for rapidly recovering from radiation induced errors in reconfigurable hardware.

In addition to the payload boards, there is a structural payload: RAMSES, a rapid manufactured thermoplastic CubeSat structure that will demonstrate the application of 3-D printed structures in the space environment.

This paper will give an overview to the UNSW EC0 CubeSat project, with the system design, the payloads and the main experiments discussed. Experiment methodology will be presented for the UNSW/NICTA payloads as well as the expected results from these at the completion of the program.

Design and Tests of the Coilable Mast of BUAASAT

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BUAASAT is a microsatellite designed by students of Beihang University (BUAA) which will be launched in 2014. One of its missions is to verify the deployment of the self-designed coilable mast. As a deployable truss, the coilable mast can be stowed to a small volume on ground, then deploy in orbit to realize the gravity gradient stabilization. This paper presents the structure design and performance tests of the coilable mast of BUAASAT.

The triangle-section coilable mast consists of battens, three continuous longerons, and diagonals. When bending the longerons along the circumferential direction, the coilable mast becomes compressed and strain energy is stored inside. The compression ratio can be 20:1. A Lock & Release Mechanism is to lock the coilable mast before deployment. And the deployment process is controlled by a rope, of which one end is fixed to the top of the mast, and the other end is connected to a damper to reduce the velocity and shock during the deployment. To avoid deployment failures caused by damper problems, a Thermal Knife is designed to cut off the rope between the damper and the top of the coilable mast.

Several tests are conducted to verify the performance of the coilable mast. The deployment can be finished in 20 s, with an average force around 10 N and periodic shocks about 50 N. It also works well in vibration and changeable thermal environments. The Lock & Release Mechanism can lock and unlock the coilable mast reliably and the Thermal Knife can cut off the rope in 10 s under the voltage of 12 V. Above all, the coilable mast is quite available and reliable for the BUAASAT mission.

Session 3

Micropropulsion Subsystems,

Formation Flying

From Delfi-n3Xt to the DelFFi Formation Flying Mission: The Next Step of the Delfi Programme

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In the recent two decades, very small satellites, such as CubeSats, are attracting more and more attention from academia, industries and space agencies due to their low cost, short development cycle and promising capability. Currently, most CubeSat missions are used for technology demonstrations or education, which only explore the capability of an individual satellite. However, the capability of CubeSats can be extremely enhanced by flying a cluster of satellites. For example, QB50, now under development, is involving 50 2U and 3U CubeSats. The proposed OLFAR (Orbiting Low-Frequency Antennas for Radio astronomy) mission requires a large number (30 or more) of identical 3U CubeSats, all with propulsion capability.

This paper provides an update of the Delfi programme of the Delft University of Technology. Delfi-C3, the first CubeSat in the Delfi programme, was launched on 29 April 2008 and is still operational after more than five years. Delfi-n3Xt, the second Delfi CubeSat, has been completed in January 2013 and is waiting for launch. The perspective of TU Delft on future small satellites motivated DelFFi, the third Delfi CubeSat mission, which is expected to be launched in 2015 within the QB50 framework and to demonstrate autonomous formation flying using two CubeSats, named Delta and Phi.

The first part of this paper provides an overview of results and lessons learned from the development and the mission implementations of the Delfi-C3 and Delfi-n3Xt satellites, with emphasis on subsystem development, satellite design, Assembly, Integration and Test (AIT) and project management.

The second part of the paper presents the differences and improvements from Delfi-C3 and Delfi-n3Xt towards DelFFi. One of the important improvements is an advanced version of the Attitude Determination and Control Subsystem (ADCS) with sensors and actuators for 3-axis control. Delfi-C3 has no active attitude control, and on Delfi-n3Xt 3-axis attitude is only an experiment. While on the two DelFFi satellites, a more mature ADCS will be an integrated part of the platform. Another improvement is on the project management, where an innovative “spiral development” strategy is utilized. Different from the traditional phase-based project management process, in the DelFFi development several design cycles will be implemented and in each cycle improvements are applied to only part of the satellite. This strategy will provide every student with an opportunity of performing end-to-end systems engineering within their limited thesis work period, which is extremely preferred for training purposes.

The third part of the paper focuses on the payloads of DelFFi that enable the autonomous formation flying. Here the technology developments are threefold

- Communicating, which concerns inter-satellite communication and ranging using an innovative and greatly miniaturized device,
- Processing, which utilizes multi-agent based artificial intelligence technology for cooperative control of the two CubeSats,
- Actuating, which performs formation control using a solid cool gas/micro-resistojet combined propulsion system with high volume efficiency and a specific impulse at 150 s.

Details of these technology developments are addressed.

Miniaturized Pulsed Plasma Thrusters (µPPT) and Field Emission Electric Propulsion (FEEP) for Nanosatellites

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Nanosatellites have evolved over the last few years to powerful instruments not only for educational purposes but also for scientific research and new technology developments. As a consequence, mission complexity of nanosatellites has increased tremendously in recent years, but due to limited attitude control and the lack of Δv capability, their application field is still limited. The volume, mass and power budget limitations complicate the utilization of conventional propulsion systems, and many propulsion technologies, in particular chemical propulsion, are not suitable for miniaturization. In this paper, the theoretical and experimental efforts to develop a miniaturized Pulsed Plasma Thruster (µPPT) and advanced Field Emission Electric Propulsion (FEEP) for attitude and orbit control are presented.

The Pulsed Plasma Thruster (PPT) is suitable for such an application due to its mechanical simplicity and low power requirements. However, though several efforts have been ongoing to develop such a system, in general, they lack the required miniaturization and lifetime. The µPPT propulsion system developed at FOTEC for the 2U Pegasus CubeSat consists of four independently controllable thrusters installed on a single printed circuit board. Since PPTs do not require active heating, virtually no lead time is required to activate the propulsion system. Depending on the power budget of the spacecraft, the ignition frequency can easily be adapted. With a total mass of less than 300 g and a lifetime of up to one million discharges per thruster, the module is offering superior performance. The directly measured total impulse is 7 µNs, on average, which enables active attitude control of CubeSats and minor orbital changes.

The Field Emission Electric Propulsion (FEEP) system developed at the Austrian Research Center (ARC) is suitable for 2U and 3U CubeSats and its power demand is 4 W. The thrust range is between 30 and 100 µN and could already be verified. The volume of the system, including the Power Processing Unit (PPU), is roughly 700 cm^3 and fits in a standardized CubeSat structure. The past and ongoing development of this system and its experimental investigations are summarized.

Micropropulsion System with Closed-Loop Thrust Control

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As CubeSats are about to pass the point of merely educational and technical demonstration purposes, propulsion capability is becoming more important in order to enable more advanced missions such as formation flying, orbit raising or de-orbit capability. To date, roughly 100 CubeSats have been launched, but only very few with any propulsion capability on board.

NanoSpace is currently developing a propulsion module that can be fitted onto virtually any CubeSat via the standard payload interface. The propulsion module contains propellant storage, a feed system and four proportional thrusters. The complete system is packed into a 10x10x3cm module that weighs about 250 g including propellant. The propellant is butane.

The key technology to achieve this is MEMS (Micro-Electro-Mechanical Systems). MEMS is in this case an enabling technology to minimize mass, volume and power, which are the driving requirements for any subsystem intended for a CubeSat.

Closed-loop thrust control is achieved by implementing a mass flow sensor in the MEMS thruster. This enables the system to measure delivered thrust in real time and use this data in a control loop for the proportional thruster valve. This concept has been successfully developed and tested and highly improves the functionality of the thruster. As an example, thrust resolution better than 0.1 µN has been demonstrated. With this technology, precise formation flying, docking and drag-free flight is within reach also for nanosatellites.

The ongoing development of the CubeSat propulsion module has a lot of heritage from the MEMS-based cold gas micropropulsion system developed for the two Prisma satellites flying in formation that were launched on 15 June 2010. The Prisma micropropulsion system had the same proportional MEMS thrusters but did not have the closed-loop thrust control that will be presented in detail in this paper.

Session 4

Attitude Determination and Control Subsystems

BeEagleSat Attitude Determination and Control System

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BeEagleSat is a double unit CubeSat to be launched in 2015 as part of the QB50 Project, an international network of 50 CubeSats aiming at long-duration exploration of the lower thermosphere. According to the mission region, the CubeSats will face high disturbance torques and short lifetime due to drag. Besides, the CubeSats carrying the science sensors shall have an attitude control with pointing accuracy of ±10° and pointing knowledge of ±2° from its initial launch altitude at 380-400 km down to at least 200 km. An Attitude Determination and Control Subsystem (ADCS) is being developed at Istanbul Technical University for de-tumbling the satellite after deployment, pointing the satellite in a sensitive attitude for recovering it from any spin-ups during the mission.

An Earth-pointing satellite will have a surface normal tangent to the trajectory in the velocity vector's direction for a circular and unperturbed orbit, the second surface normal vector perpendicular to the orbital plane, and the third one in the nadir direction. The designed three-axis attitude control system will point BeEagleSat to the Earth so that the long body axis is aligned with the velocity vector. In such an orientiation, the decay duration of the satellite is maximized. Restricted available actuation power due to the low solar panel area and restricted volume for mechanical actuators such as reaction wheels point out the usage of a magnetic actuators triad as the most convenient attitude control system solution. The simulation trials showed that the proposed purely magnetic attitude control system driven by developed control algorithms is feasible between 350 and 140 km. Below 140 km, the desired orientation can be kept by using a pitch momentum wheel aided by the magnetic actuators. A three-axis magnetometer, an algorithm estimating the Sun vector from solar panel voltages, and a three-axis gyroscope constitute the attitude determination system together with a filtering algorithm. Attitude determination performance depends on accuracies of sensors selected by regarding the power and volume restrictions and the utilized system and measurement models. In addition, a three-axis accelerometer placed at the center of mass will sense the deceleration due to atmospheric drag.

Evaluation of In-Orbit Aerodynamic Stability Systems for CubeSats

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The Attitude Determination and Control Subsystem (ADCS) is one of the important subsystems on board a satellite. Precise attitude knowledge is crucial for several types of tasks like Earth observation or high data-rate communication using antennas with a narrow transmission cone. Due to miniaturization, common ADCS elements, like star trackers and Sun sensors for attitude determination and magnetorquers and reaction wheels for controlling, are also available nowadays for CubeSats. However, the control torques which can be generated by the actuators are limited due to the constraints in terms of mass, volume and power consumption. New developments like thrusters based on solid propulsion or arc jets underlie the same restrictions and can therefore only provide a small thrust. As a result, the standard ADCS on CubeSats can only provide stability up to a certain altitude limit. At very low altitudes in a low-Earth orbit, the increased disturbance torques cannot be coped with by the actuators any more.

VKI is developing the re-entry CubeSat QARMAN (QubeSat for Aerothermodynamic Research and Measurements on AblatioN), in the framework of QB50 to perform a re-entry down to 50 km of altitude and take measurements on the radiation and ablation of the thermal protection system. To ensure a successful mission, an Aerodynamic Stability and De-orbiting System (AeroSDS) is proposed for QARMAN to provide permanent stability without power consumption and only a slight increase in mass. Different designs for the system have been studied using Direct Simulation Monte Carlo simulations to obtain the aerodynamic properties necessary for the lifetime and stability analysis using six-degree-of-freedom simulations. Suitable designs for the orbit phase will be presented together with the aerodynamic characterization and the simulation results.

Selection of Design Parameters of Aerodynamically Stabilized Nanosatellite for Thermosphere Research within the QB50 Project

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To solve some important scientific and applied problems, for example, the measurements of atmospheric parameters in the QB50 Project, it is necessary to stabilize the nanosatellite attitude in orbit. This can conveniently be achieved by using a passive stabilization system in which the aerodynamic moment is used as the control moment. This can be realized by a satellite design transformation, where the center of pressure is shifted aft (in the anti-flight direction) while keeping the position of the satellite center of mass almost unchanged, thereby creating a static stability situation.

In launch configuration the nanosatellite has the shape of a 2U CubeSat. Some time after deployment, the CubeSat shape is transformed to become a 3U CubeSat. The satellite's center of mass is only displaced by a small amount, but the center of pressure moves from the initial position by about 5 cm in the anti-flight direction. For dispersion of fluctuation, energy hysteresis cores which interact with the Earth magnetic field (EMF) are used and extinguish fluctuations. For ensuring the required accuracy of satellite longitudinal axis orientation it is necessary to pick up optimum performances of hysteresis core system so that, as a result of interaction with the EMF, the longitudinal axis does not considerably deviate from the required position.

The existence domains of the nanosatellite were investigated, depending on aerodynamic orientation system parameters, hysteresis core parameters, the satellite inertia moments, atmosphere density, etc. In particular, for a polar orbit the stable motion characteristics were numerically obtained. A technique for the selection of nanosatellite design parameters was developed, providing the required accuracy of the nanosatellite longitudinal axis orientation, using the velocity vector, depending on initial motion conditions (initial orientation and initial angular velocity) and required time of transient.

The selection of the nanosatellite design parameters applying to the QB50 Project is carried out and the requirements to the nanosatellite separation system to meet the restrictions on initial motion conditions are formulated.

Low-Cost Star Tracker with Highly Efficient Algorithms

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As CubeSats are increasingly showing their potential for more complex missions, such as observation and formation flying missions, the importance of an accurate and efficient attitude determination and control system becomes ever greater. Currently, CubeSats mainly use magnetometers, Sun sensors and gyroscopes to determine the attitude of the spacecraft. These components have a low cost, but also yield limited accuracy.

The most accurate absolute attitude determination sensor is the star tracker. This sensor can determine the attitude with an accuracy in the range of a couple of arc seconds. Despite this superior performance, the star tracker is seldom used in smaller satellites, mainly because of its high cost, size and power consumption.

At KU Leuven, we have recognized this issue and are developing a low-cost star tracker for CubeSats. One way to lower the cost of this sensor is to lower the computational complexity of the algorithms. This way, the requirements on the computational hardware are reduced and the cost and power consumption can be lowered. The star tracker will use novel, highly efficient algorithms, which were developed at KU Leuven. We will discuss two of these algorithms, the centroiding algorithm and the tracking algorithm in depth, and will focus on their efficiency.

The centroiding algorithm determines the centroid of each star as accurately as possible. The proposed algorithm fits a model of the point spread function through the data and minimizes the distance between model and measured data. This leads to an accuracy that is as high as that of the most accurate centroiding methods, while the computational cost is in the range of that of the fastest available methods.

The tracking algorithm determines the attitude quaternion by minimizing the distance between corresponding image star and database star pairs. The accuracy and robustness is similar to that of the most accurate and robust methods, while the computational cost is significantly lower than that of the fastest state-of-the-art method.

Both algorithms minimize a cost function to obtain their result. Traditionally, this minimization is performed using numerical, iterative methods. Our proposed approaches determine the minimum using an analytical solution, which leads to closed form expressions that can be very efficiently calculated online. With this novel approach, our tracking algorithm is around 30% faster and our centroiding algorithm is 40 times faster than the state-of-the-art methods that yield similar accuracy. This high efficiency makes these new algorithms ideally suited for CubeSat applications.

Rapid Design and Verification of Miniature Solar Panel Integrated Sun Sensors

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Sun sensors are often used in satellite Attitude Determination and Control Systems (ADCS). These or any other sensors offering high-accuracy absolute attitude determination, e.g. star trackers and Earth horizon sensors, need surface area from the exterior of the satellite. This exterior area is typically used for body-mounted solar panels for power generation. Thus, integrating Sun sensors limits the satellite's power budget. This is especially true on pico- and nanosatellites, which typically have a very limited exterior area. Most current Sun sensor designs are relatively large to be used in such satellites with a limited power budget, generating a need for smaller sensors. Due to the miniaturization of consumer electronics in the past years, many small commercial sensors have become available. These commercial-off-the-shelf (COTS) components can be utilized in implementing miniature satellite systems at a relatively low cost.

This paper presents a Sun sensor design suitable for pico- and nanosatellites, utilizing COTS sensor components. These sensors can be integrated in the solar panels of most satellites, without having to use any exterior area needed for their solar cells. The Sun sensor consists of a commercial solar angle sensor with an Atmega328 microcontroller and uses an I^2C data bus to communicate with the satellite's ADCS. In spite of their small required surface area of only about 5 x 5 mm^2, the estimated attitude determination accuracy is below 5º, which allows using them in many satellite mission applications. The sensors are, for example, used in the Aalto-1 satellite mission's electrostatic plasma brake/sail experiment, requiring a 200 deg/s spin-rate and a 10º attitude control accuracy. They are also used as a backup for the ADCS's star tracker.

Nanosatellite projects are usually fast track compared with conventional satellite projects. This limits the available time for subsystem design and verification. Space qualification of COTS components can be especially time consuming and requires methods for early verification of the designs. Thus, this paper also presents a rapid design and verification strategy using the Arduino prototyping environment.

Achieving high pointing knowledge throughout eclipse in QB50 application

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This paper presents the capabilities of the CubeSat ADCS subsystem developed by SSBV, focusing in particular on the pointing performance obtainable on a QB50 mission CubeSat. The QB50 mission requires a challenging ADCS capability with a pointing knowledge at the performance limit of current capability. Accurate attitude knowledge of a CubeSat is especially demanding to achieve in the eclipse phase. The solution proposed in this paper is based on a set of sensors and actuators which can achieve sub-degree attitude knowledge alongside 3-axis control. The design includes up to 6 Sun sensors, a high sensitivity magnetometer, a GPS receiver, stellar gyro and 3 MEMS gyros.

The use of a stellar gyro, which assures high performance during eclipse, and a GPS receiver, which gives the best attitude determination performance from the magnetometer, are seen as providing the optimum solution for QB50 if used in combination with high accuracy Sun sensors, MEMS gyro and a precision magnetometer.

The actuators include metal core magnetorquers and a single momentum wheel. The introduction of the wheel gives gyroscopic stiffness once the required ram direction attitude is reached, guaranteeing good pointing stability. Moreover, the variation of speed of the wheel can be used to perform efficient along-track manoeuvres if required. The architecture allows the overall system to achieve tightly constrained dimensions within the volume of 2 standard PC 104 boards.

Influence of the Gravitational Moment on the Magnetic Stabilization of CubeSats in equatorial orbits

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Nowadays small satellites are widely used for space exploration and Earth observation because of the attractive short period of design and low cost. That research requires the investigation of the problem of attitude control and stabilization of rotational motion of these satellites.

In this paper the problem of the magnetic stabilization of a magnetized CubeSat in an equatorial, circular orbit is considered. The Earth's magnetic field is modeled by a direct dipole, so the vector of the geomagnetic intensity **H** has a constant direction and value in all points of the satellite's orbit and is orthogonal to the CubeSat's equatorial orbital plane.

There are strong magnets on board the satellite. Therefore, its rotational motion is defined basically by interaction of the magnetic moment of the satellite and the Earth's magnetic field.

The effect of the gravitational torque on the magnetic stabilization is investigated. Analytical results are confirmed by numerical simulation of the satellite attitude motion. By integrating the differential equations of the CubeSat's attitude motion the components of the absolute angular speed at the main central axes of inertia and the Euler angles are found. Their graphs show that there is stabilization of angular velocity, angle of precession and proper rotation angle during passive magnetic stabilization. However, the nutation angle increases, which indicates the occurrence of nutation oscillations. Thus, it is established that the passive magnetic stabilization accompanied by nutation oscillations which are complex and have variable amplitude. Nutation oscillations are damped by the flywheel systems installed along the principal axes of inertia of the CubeSat. It is found that the time to reach magnetic stabilization when considering the gravitational moment is longer than without it.

The results can be used to predict and study the evolution of the rotational motion of a satellite and its stability and may have implications for engineering developments in the space industry.

Characterization of Electronic Commutated Brushless DC Micromotors as Actuators in Satellite Attitude Control Systems

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Operational Characterization for actuators based on electronic commutation brushless DC motors are presented. Normally with these motors, speed control using Pulse Width Modulation (PWM) in an open or closed loop mode is used, but the torque value developed by the motor in each operational state is not specified, as required by attitude control laws which specify torque to be provided to the spacecraft. In this paper, test protocols and results are developed which explore the use of ordinary PWM drivers in an open or closed loop mode, “modulating” input voltage to the driver and On and Off time, obtaining average torques which are calculated establishing motor torque limits. On each sample time this voltage and times are calculated according to the value generated by the control law. Follow up of respective control law will in general result in varying sample times that may stay within proper limits (compared to response time constants of dynamic satellite system). Simulations and test results exerted on a CubeSat system are presented. An immediate consequence of this work is the possibility of using “common” EC brushless DC motors instead of reaction wheels as actuators in the Attitude Determination and Control Subsystem (ADCS), thereby reducing significantly the cost and space used.

This paper discusses the following aspects

- Introducing an ADCS used for simulation and testing: The determination system is based on an extended Kalman filter using two reference vectors, the Earth´s magnetic field and a solar vector with albedo correction. Also, angular speed is measured. Determined attitude is the input for a sliding control which generates the control law as a voltage signal for the actuators module, which is received directly at driver´s input (set value voltage). A simulation is implemented in MATLAB and SIMULINK where all measurements are simulated as well.
- A dynamic electro-mechanical model for an electronic commutation brushless DC micromotor (MAXON EC 10 Flat) is exposed, respective parameters as specified by manufacturer are used in the model, providing behavioral curves.
- Torque and speed dynamic equations are developed according to motor characteristics and nominal operating conditions.
- PWM driver (MAXON DEC module 24-2) specifications are presented and both operating modes are presented. Experimental voltage versus speed curves are given.
- How to obtain a specified torque from any operating point is presented and an algorithm for it is provided.
- This algorithm is incorporated in a simulation based on MATLAB and SIMULINK.

A Test Bench for Attitude and Orbit Control Systems of CubeSats

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To support the development and testing of on-board software for attitude and orbit control, Electrical Ground Support Equipment (EGSE) systems are commonly used by larger satellites. However, with increasing complexity of CubeSat applications and missions, the need for an attitude and (possibly) orbit control test bench increases. This abstract presents a demonstration test bench developed at NLR as part of its internally funded research program. This test bench provides the basis to verify the attitude and orbit control systems for the QB50 DelFFi mission of TU Delft, where two CubeSats are flying in formation using miniaturized thrusters.

In the first phase of a space project, a mission is simulated in, for instance, Matlab/Simulink. In later phases, this simulation is then transformed into a real-time simulator for a test bench with hardware in the loop. Several tools and standards are in place to ease this conversion process.

The presentation will show how an example targeting attitude control scenario of a small satellite is used to evaluate the conversion process from Matlab simulations towards a real-time test bench.

Firstly, a spacecraft environment and a satellite model (including on-board software for attitude control) are developed in Matlab/Simulink. Consequently, these models are converted to C using Matlab's Real Time Workshop (RTW) module. The Model-Oriented Software Automatic Interface Converter (MOSAIC) then converts the C-code into SMP2 models, ready for integration into the EuroSim real-time simulation environment.

In the next step, the attitude control functions are rewritten from the embedded Matlab scripts into the C/C++- programming language as part of the operational on-board software. In order to test/debug the attitude control, this software was written such that it can run both on a target computer board and inside EuroSim as an additional model in parallel with the converted Matlab algorithms. This last feature enables a comparison of the source code from RTW with the code imported from embedded Matlab.

Finally, after successful validation steps, the on-board attitude control software is executed on the target on-board computer, where data is exchanged with the simulator via a local area network. For the future, other interfaces between the simulator and the target computer, such as I2C, are planned.

3-Axis Set-Up for Testing the ADCS Subsystem

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The Attitude Determination and Control Subsystem (ADCS) is a crucial system for any satellite but there seems to exist no definitive way to test such a system. The sensors can be tested on a breadboard or on a PCB. Most sensors/modules procured are Commercial-Off-The-Shelf (COTS) products. All of them are calibrated before shipment. However, when put together and looked upon as a system it is not the same. For a CubeSat mission reliability is a key factor and that can be only achieved by testing. The most crucial function of the ADCS is detumbling of the satellite after orbital insertion. This algorithm can be certainly simulated in SIMULINK. The objective of the work is to collectively test both components of the ADCS subsystem and some of its crucial algorithms in a test set-up. The test set-up should contain features to test at least some of the ADCS components.

In order to achieve this, the first step is to create a single-axis stabilization system using a magnetometer and a servo. This test allows us to perform unit testing on the magnetometer, which opens a path for further testing of other ADCS components, such as a Sun sensor and a digital gyroscope. In a single-axis test set-up, the servo acts a magnetorquer, since unit testing of the same in Earth’s gravity is little trivial.

The next step is to build a three-axes test bed which contains all primary sensors in the ADCS subsystem and once again we use servos instead of a magnetorquer. In this set-up, the B-dot algorithm for detumbling of the satellite can be tested for validation testing of the software, basically system testing the entire ADCS subsystem without magnetorquer.

Session 5

Telecommunications, Ground Stations, Ground Station Networks

Towards a Ground Station Network for QB50

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A significant challenge facing many CubeSat missions is how to maximize the volume of payload data returned to the ground. With a single ground station, the theoretical maximum data return is proportional to the amount of time the satellite is within range of it, and the bandwidth of the communication channel. The contact time is constrained by the geometry of the spacecraft orbit in relation to the ground station location, whilst the communications bandwidth is constrained by the allocation of precious radio frequency resource.

For the QB50 mission, with its very low-Earth orbits (below 200 km towards the end of the mission) and UHF downlink (typically 9.6 kbps), the science payload data return would be severely limited, perhaps to less than 1% of the data potentially available on-board. In other words, 99% of the science data generated by the QB50 CubeSats would be lost.

However, that figure could be improved significantly by setting up a network of collaborating ground stations to extend the total contact time, as has been envisaged by the Global Educational Network for Satellite Operations (GENSO). All 50 CubeSat teams participating in QB50, plus a few other teams in different parts of the world, have expressed their willingness to make one or more ground stations available for such a network, bringing the current total to about 120 ground stations. The supporting ground system infrastructure will be specially adapted to QB50 and is to be commissioned and tested during 2014 in order to be ready for full operation in 2015.

This paper reviews some of the lessons learned from GENSO and some of the special characteristics of QB50, that should be taken into account. Topics include compatibility, availability and integration of ground stations, and approaches to mission planning, scheduling and booking of resources. Ultimately, the total QB50 data return may also depend on factors such as the concept of operations of individual CubeSats, accuracy of orbit prediction, availability of on-board power and the extent to which downlink transmissions can be planned and scheduled in advance.

Iterative Simulation of the BUSAT-1 Communications Segment as an Element of QB50 and GENSO Networks

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BUSAT-1, the Beihang University's 2U CubeSat in the QB50 Project, is being developed by a multidisciplinary team of graduate students. The fact of flying in a 90-380 km altitude orbit among 50 satellites has introduced unique requirements in developing this space system, in particular its communications segment. It includes the communications subsystem of BUSAT-1 and a dedicated ground station accepted as a node in the Global Educational Network for Satellite Operations (GENSO). This paper aims to illustrate the iterative simulation of satellite communications which is employed to analyse challenges and design decisions in devising the communications segment.

The mentioned simulation is essential to find out not only the design margins but also the satellite-to-satellite or ground-station-to-satellite RF interference. In addition, the modelling can be valuable for gap analysis and operation scheduling of GENSO. Planning to be a first-class decision making tool, the model has considered antenna patterns, 3D slant range, Doppler effect and the satellite's attitude and orbit which are highly dependent on the separation scenario from launch vehicle. A model is applied in developing the simulation to integrate an iterative design of 50 satellites in a top-down approach and to extract solutions from bottom to up.

The first loop of the simulation has been conducted for only the communications segment of the BUSAT-1 on numerical analysis software. Using a COTS transceiver with space heritage has been the important decision that results in UHF uplink and VHF downlink. Trade off has been conducted on antenna configuration, downlink data rate and the minimum elevation of the ground station through combined data-link budget analysis. The analysis shows that the ground station has access to the satellites in non-zenith and low elevation angle passes in more than 50% of the mission period.

The second simulation loop assesses the communications of all the QB50 satellites to the dedicated ground station. The results point out the need of multiple tracking or tight tracking scheduling and utilizing generic software/hardware for base-band (de)modulation and (de)coding in the ground station to serve all the teams. In addition, verification and a test operation of GENSO nodes before the QB50 launch is emphasized.

Finally, the paper concludes the results of the first two simulation loops to plan the next loops, including the BUSAT-1 access to GENSO nodes and full-scale communications among all the satellites and the GENSO nodes. Furthermore, the required collaboration among the CubeSat teams and the QB50 working groups is addressed to maximize the effectiveness of the simulation.

Design and Implementation of a Network of One Picosatellite and Four Ground Stations

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The project Picosatellite "CubeSat-UD Colombia 1" has the objective to develop an academic picosatellite, called Colombia-1. The goal of Colombia-1 is to transmit from one point to another electrocardiographic signals digitized and packaged in the AX.25 protocol. In order to reach this goal a network of four ground stations, located in different parts of the country, was implemented. The picosatellite always emits a beacon signal and, when the signal is detected by a ground station, the satellite immediately tries to bind in AX.25. If the connection is successfully established priority data are downloaded to the ground station before the station sends data.

This paper is intended to present how the link and the communication protocol were implemented. Initially, it was implemented in the laboratory network in a fence and then passed as a wireless network. To achieve efficient connection establishment was required to design an external TNC (Terminal Node Controller) to a Kenwood TM-700 radio and in the picosatellite's YAESU VX-3 radio, that is responsible to manage communication between the ground station and the CubeSat which main objectives are to establish a radio link, ensuring correct exchange of information between the two actors and finalize the radio link.

When the signal generated by the satellite beacon is detected the automatic link establishment starts immediately. If it is the destination station, which has priority in downloading information that is housed at the satellite, after completion of download Earth station proceeds to send the new data through the AX.25 communications protocol. The communications system to handle this protocol also must include a protocol for exchange of information with the central card, antenna deployment system in flight, frequency radio system and interface between the digital and radio frequency system. AX.25 protocol was implemented with NRZI, and the hardware was implemented based on the MSP430F1612 microcontroller Texas Instruments, the main card use a hardware protocol based in RS-232 modem signals. The implementation of both TNC satellite and ground station station is performed based on the FX614 modem, which makes Bell 202 FSK modulation.

Optimizing Data Download to a Cluster of Networked Ground Stations: A Model for the QB50 Project

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One of the QB50 mission challenges is to provide enough data download capabilities in order to get all (or the maximum of) scientific, telemetry, and housekeeping data supplied by all 50 satellites. Given the expected orbit inclination and altitude, regarding the concentration of ground stations, the satellites will fly over three basically different types of regions: empty, such as the oceans and the polar regions; sparse, with only a few stations; and clustered, with many stations relatively close, such as in Europe and Brazil.

In clustered regions the satellites' footprints will frequently cover more than one station, thus creating the problem of deciding how much data each station is going to download from each satellite, since their ranges overlap in some periods of the flight. This work presents an 'orchestration' model for optimizing the total volume of data to be transmitted to a cluster of ground stations, considering the main characteristics of the QB50 mission.

The main result of the model is to determine, for a given pass, the optimal sequence of antenna movements, with respective start and end points. The model provides an objective function that considers the quality of transmission, influenced by the view angle and distance to the orbit, and takes into account the following constraints

- overlapping of ground stations range,
- antenna movement delays and limitations,
- establishment of an equilibrium between the previous constraints and the a) data available to download and b) for each satellite, the power available for transmission.

Additionally, it is possible to prioritize the download from a given satellite to a given ground station by setting up the appropriate coefficients in the objective function.

This model is implemented by a software that compiles all the necessary information and provides functionalities for simulating different scenarios and implementing the most appropriate.

Web Service for Satellite Tracking and Prediction for the 14-BISAT Project

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The 14-BISAT Project will be one of the first Brazilian CubeSat projects. Its main goal is educational. The 2U 14-BISAT CubeSat is part of the QB50 Project, carrying one of the standard science sensor sets. As part of the project, the 14-BISAT ground segment will involve a total of at least 12 ground stations. These stations will be distributed mostly on Brazilian territory, while a couple of them are placed in Portugal. Coordination among them will be made from Instituto Federal Fluminense (IFF), which will host the leading ground station and the 14-BISAT team.

This paper presents a proposal to automate this coordination using web service as solution. The web service will have a satellite tracking algorithm that calculates the position of the orbiting satellites at any time and will centralize the information that will be downloaded from the satellites. Also, it will calculate where the antennas should be pointed in space to receive the satellite signals.

This algorithm is based on the SGP4 model that takes into consideration the disturbing forces constantly affecting the satellite trajectory, such as the gravitational attraction of the Sun, the Moon, and the Earth. The paper presents also the web application for satellite tracking and prediction, the satellite orbit visualization, the satellite motion controller and other functions.

GAMANET: Networking QB50 – First Results

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GAMANET is an ambitious endeavour in space communications being proposed within the scope of QB50. Its challenge is the creation of the largest ad-hoc communications network ever in space. Its goal is to bring the networking capability to satellite constellations. QB50 presents itself as the ideal mission to test such technologies, gathering worldwide CubeSats around a common communications platform. As GAMANET participants, QB50 CubeSat teams will have the networking resources required to send commands from ground and to receive satellite telemetry, even when their own satellites are not within range of their stations. Joining CubeSats and ground stations in a seamless communications network, the GAMANET initiative aims both to validate innovative communication technologies in space and to improve the overall QB50 communications and scientific results.

GAMANET will have two segments, connected seamlessly together: the space segment and the ground segment. Each segment will have different, though similar devices and different interfaces. GAMANET's enabling device is GAMALINK, an advanced communications platform relying on the flexibility of Software-Defined Radio. Present on every GAMANET node, whether a CubeSat or a ground station, GAMALINK empowers the formation of mobile wireless ad-hoc networks in space, benefitting from technology that has already been vastly tested to provide connectivity in the most demanding environments on the ground. GAMALINK also delivers accurate position determination based on GPS, which provides absolute position and timing information that may be used to achieve synchronisation between satellites. Optionally, it can also include an experimental radio-based attitude determination algorithm, which may be used as an extra attitude determination sensor for improved redundancy and/or accuracy.

In this presentation, the concept and its benefits for CubeSat network and constellation missions together with the potential of the involved technologies will be further detailed. The first prototype results of GAMANET will be presented and the next steps towards validation will be described.

Optimization of Ground Station Locations for the Tracking of Nanosatellites using 3D Modelling Techniques

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The increasing number of small satellite and nanosatellite missions in low-Earth orbits raises the need for a reliable communication link and to maximize the visibility time between the satellite and the ground station. Satellites in low orbits are visible from the ground station only for a few minutes per day. In addition, small satellites also have limitations in the amount of power available to download data to ground stations, and hence need to optimize their concept of operations to maximize the communication times with the ground stations.

The study presented in this paper offers an analysis for selecting ground station sites, using geographical 3D modelling techniques. The digital model obtained is represented in a 3D thematic map with internal and spatial variables which affect, distort or hinder communication, regarding the theoretical location of the antenna and its surrounding environment. In addition, the application of this study in an operating station allows to visualize the existing visibility windows and to develop recommendations to redesign its location for satellite tracking to improve effectiveness.

In addition, this study will show experimental results that have been obtained for a ground station located at ETSIT-UPM with the aim of achieving the optimal site of the ground station. This experimental analysis will determine that optimization of the satellite elevation mask, in its AOS and LOS azimuths along the horizon visible from the antenna, increases the communication time with the ground station. Issues such as orography, buildings, and other obstacles surrounding the antenna will be considered in the study and its impact on satellite visibility will be evaluated. In conclusion, optimal configuration of the antenna elevation mask maximizes data download, and hence helps to meet the requirements of the mission. This fact is especially important in complex missions that include many small satellites, such as QB50, where one ground station would be able to track several satellites even simultaneously.

Design of an embedded module for pictures transmission for CubeSat

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Since 2013, INSSET is involved in a project to design all the modules for a picosatellite aimed at a launch in 2016. In this paper, we describe an innovative module, which will be embedded in our CubeSat in order to take images and to transmit them to the ground station.

This system is based on an adaptation of a previous contribution dedicated to ham radio operators during emergency rescue operations (FNRASEC). The main advantage of our system is that it just needs our software porting (as a subroutine in the OBC with an ARM based processor) without additional hardware, except for a link with the radio transmitter. Therefore, this product meets the principal requirements of spatial context in terms of mass, price, size and power consumption. The protocol chosen allows picture transmission over an audio radio channel with a narrow bandwidth as used in telemetry or AF radio transponder/repeater.

The image is transmitted line by line with RGB (or YUV) pixel format. Depending on the mode used, the image resolution can vary from 128x128 pixels in white/black to 320x256 with color pixels with transmission time from 8 to 140 seconds.

Our goal is to provide an easy integration of this system as a free source code for ARM-based processor for the OBC and as a stand-alone subsystem grouping all the radio functionalities (telemetry, TT&C, CTCSS, DTMF, ham radio repeater). The image acquisition phase will use a conventional communication bus such as RS232, I2C, SPI, CAN connected to a low-cost digital camera, and the SSTV modulation just needs to be connected to the audio input of the transmitter of the TT&C subsystem.

Some other functionalities as information incrustation in the transmitted picture (date, position, sensors value, etc.) have been validated and are operational. The other advantage of this system is that the reception phase does not need dedicated equipment; it only uses free ham radio software and a single receiver with the AF output connected to the micro (or line) input of a computer.

In the paper we will present in detail the SSTV protocol, the optimum use and programming of the internal peripherals of the ARM processor (timer, interrupt, pixels codification and signal generation via PWM principle) to meet the crucial requirement of SSTV signal timing, the study of the radio link and the effect of orbital parameters in the decoding phase.

Advanced Autonomy Concept for Low-Cost Ground Stations

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A CubeSat mission requires an implementation of a satellite ground station in order to control the satellite. Due to the commonly low budgets of CubeSat missions an application of professional and expensive hardware is not feasible. In the scope of the recent success of small satellite missions many low-cost ground stations were established. In this context low-cost means that they are mainly composed of commercial off-the-shelf components.

These ground stations are typically used by their associated research institutes for providing access to their small satellites. In the last few years, several projects were initiated to network these stations (e.g. the ESA project GENSO or the Japanese GSN initiative). While these projects try to use standardised software for ground station operation, we developed a concept which has been well adapted for the ground station of the University of Würzburg.

A ground station design with highly autonomous functions has been implemented without custom-built hardware. The entire ground station serves as an independent communication node to provide access to the CubeSats of the UWE series. This design allows commanding of multiple satellites from almost every distant computer with internet access. The ground station itself is responsible for establishing and maintaining the communication link. Therefore, the ground station system performs all necessary tasks such as tracking of the antenna, correction of Doppler shift, autonomous reconfiguration, hardware monitoring, weather observation, data handling and autonomous fault correction.

The COMM Communications Subsystem of the QBito CubeSat, A Demonstrator for Gaining Hands-On Experience

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To start a CubeSat student project, it is very important to have a long-term group of students interested, and that they gain hands-on experience from the beginning, even if they are just starting their bachelor degree. ETSIT-UPM is in charge of the communications subsystem of the QBito CubeSat participating in the QB50 Project.

As a starting point for the development of the COMM communications subsystem we are making a prototype based on the Texas Instruments MSP430 platform. This microcontroller has already been successfully used in several CubeSat missions. We are also including the TI CC1120 UHF Transceiver. This will be a first prototype for the COMM subsystem that we want to keep developing and working on to become a demonstrator to show students early in their career in a simple manner the complexity behind the development of a nanosatellite and its communication subsystem.

The demonstrator prototype will be connected to several sensors; they will be managed by the MSP430. Using a request (or an automatic programmed event) their information will be sent to another similar transceiver board emulating the transmission of telecommands and telemetries. We use a Graphical User Interface (GUI) application for controlling the status and sending commands from one demonstrator to another. Our goal is to lower the difficulty curve of understanding such a system, similarly to current popular platforms like Arduino or Raspberry Pi. The demonstrator presents in a structured manner the flow of operations of a satellite. This can be used to teach not only future CubeSat team members but also to illustrate telecommunication theory seen in ETSIT-UPM degrees and to attract new students to nanosatellite projects.

Alongside academic purposes, we will use this COMM demonstrator for antenna testing, mod/cod algorithms testing and, in the future, it will be integrated with our UHF/VHF ground station.

Session 6

Orbital Dynamics,

Lifetimes for CubeSats

Probabilistic Assessment of the Orbital Lifetime of a Standard QB50 CubeSat

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QB50 is aimed at studying in situ the spatial and temporal variations of key constituents in the lower thermosphere and F layer of the ionosphere. For this purpose, a minimum of a few months lifetime is mandatory to achieve a proper temporal coverage of the collected data. The very low altitudes of the 50 CubeSats in the QB50 network makes orbital lifetime a critical aspect of the mission. Attitude requirements for standard QB50 spacecraft are intended to maximize the lifetime by minimizing their ballistic coefficient. Nonetheless, several severe uncertainty sources invalidate any deterministic estimation of the lifetime.

The first category of uncertainty sources concerns physical models. The stochastic-in-nature dynamics of the atmosphere makes a deterministic estimation of the gas composition and temperature impossible. Remarkable efforts were performed since the 1960s to gain insight into the nature of the atmosphere. Nonetheless, most atmospheric models in the literature rely on the correlation between the density and the solar and geomagnetic activities, which are stochastic processes that cannot be handled and predicted with deterministic approaches. Furthermore, a deep understanding of the mechanisms which determine the variations in the atmosphere is not achieved yet and, even if it were the case, the implementation of such a complexity in an efficient numerical code would probably be prohibitive.

The second category of uncertainty sources concerns the initial conditions. In particular, some initial orbital parameters of QB50 are not selected yet and the deployment strategy is still to be defined. Further uncertainty is also introduced by the accuracy of the launcher.

In this study, we propose a probabilistic assessment of the orbital lifetime of a standard QB50 CubeSat based on a parametric uncertainty quantification approach. For this purpose, we characterize both uncertainties in the estimation of the drag force and in the initial states. Then, a Monte Carlo propagation of these variables is implemented to achieve a probabilistic description of the orbital lifetime. Finally, we gain insight in the obtained results through a sensitivity analysis, which allows us to investigate the importance of the different uncertainty sources in the generation of the variability of the variable of interest.

Lifetime Analyses for QB50 2U CubeSats in Orbit

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QB50 has as its most important scientific objective a study of the largely unexplored lower thermosphere with a network of about forty 2U CubeSats in a string-of-pearls configuration, carrying standardized sets of science sensors for in-situ measurements. Thus, prior knowledge of the CubeSats' lifetime is important. The most valuable science data is expected to come from lower altitudes, however, this is also the most difficult region to collect data in due to the short lifetime when the orbits of CubeSats decay rapidly. A lifetime of more than three months would be highly desirable. The initial altitude of the CubeSats is one of the key parameters that affect the lifetime. For that reason the lifetime of the CubeSats is calculated for initial altitudes between 320 and 400 km, the range of altitudes under consideration for QB50. Atmospheric re-entry is assumed to occur at 90 km.

Lifetimes of CubeSats are determined using Direct Simulation Monte Carlo (DSMC) calculations for different values of the drag coefficient. In most studies the drag coefficients are taken as 2.2 for CubeSats, however, in this study the values are varied from 2.8 to 2.3, and the lifetime is calculated for 0.5 step size of the drag coefficient. Moreover, the mass will be different from CubeSat to CubeSat because the participants of QB50 will be different and the design of each CubeSats will differ too. The upper mass limit for a 2U CubeSat is 2 kg and the lower mass limit is taken as 1.7 kg for the simulations. The lifetime variation due to the mass distribution is also calculated. The analyses are made by using the WGS84 and EGM96 gravity models, the NRLMSISE-00 atmospheric density model, solar flux and monthly prediction of geomagnetic activity values. For the lifetime calculations, Systems Tool Kit (STK) Lifetime Tool is used. Also, relativistic accelerations, 2nd order oblateness correction and rotating atmosphere are included in these calculations.

The results of the study can be used to estimate the lifetimes of QB50 2U CubeSats for a range of initial altitudes and, also, for other projects which have similar initial altitudes, mass and/or ballistic coefficients.

Lifetime Analysis of CubeSats in the QB50 Network from the Perspective of Mean Orbital Elements

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The lifetimes of satellites in low-Earth orbit are seriously affected by the semi-major axis of the orbital elements. However, the osculating semi-major axis changes periodically when the J2 perturbations are considered. The oscillation amplitude of semi-major axis is about 10 km for a CubeSat orbiting the Earth at 330 km altitude, considering the J2 perturbation which affects the lifetime analysis results seriously.

Previous studies on lifetime analysis of CubeSats in the QB50 network were performed in osculating elements. This paper studies the lifetime of the CubeSats in the QB50 network from the perspective of mean orbital elements. First, the difference between mean elements and osculating elements is analysed. Then the mean elements are conversed into the osculating elements, considering the J2 perturbation. The lifetime is analyzed using satellite tool kits, considering the non-spherical gravitational perturbation of the Earth, the atmospheric drag, the solar radiation pressure and third-body perturbations.

Simulation results show that a lifetime analysis performed in mean orbital elements can avoid the inaccuracy caused by osculating orbital elements. The effect of the solar flux and spacecraft cross section on the lifetime of the CubeSats in the QB50 network is also investigated. Mean semi-major axis is optimized to ensure 90 days lifetime of the CubeSats in the QB50 network according to the predicted solar flux conditions during the operational phase of QB50.

Initial Conjunction Risk Analysis between the ISS and the QB50 Network

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For many Low-Earth Orbit (LEO) satellites the effects of the non-Keplerian forces, i.e. the deviations of the gravitational force of the Earth from that of a homogeneous sphere, gravitational forces from Sun/Moon, solar radiation pressure and air drag must be counteracted. The International Space Station (ISS) is maintained at an orbital altitude of between 330 km and 410 km. It means that the ISS is able to make orbital station keeping, if there is any collision possibility within the risk box of the ISS.

If a network of many CubeSats is launched into an orbit that is above the altitude of the ISS, there may be a danger of collision with the ISS when the orbits of the CubeSats decay due to atmospheric drag and the other perturbations. If the CubeSats deployment altitude is below the 330 km, there is a very low risk of collision between the ISS and the QB50 network. However, the new proposed QB50 initial altitude may be between 350 and 400 km. Hence, there is a need for conjunction analysis to investigate the collision risk between the ISS and the QB50 CubeSats.

The QB50 CubeSats are considered in a string-of-pearl configuration distribution and the ISS orbital movement is shown by using two line element (TLE) data for mid April 2015. The orbit propagations of both of them are calculated in Systems Tool Kit (STK), using the Advanced Conjunction Analysis Tool (AdvCAT) and the Close Approach Tool (CAT). The risk range of the ISS is taken as the well-known NASA “pizza box” risk range (±0.75x25x25 km). Moreover, ESA’s approach for collision, ±10x25x10 km ellipsoid is applied to make another analysis and this will give another opinion in order to see the risk of collision. The QB50 CubeSats risk range is taken as ±0.5x3.5x3.5 km. The box dimensions are radial x down track x cross-track defined in centric frame. With these risk ranges and using CAT and AdvCAT analyses the probability of detection and number of collision risk alerts per day will be shown. This study can be used to see initial collision risk between the QB50 network and the ISS. Further studies can be made by including other risk ranges.

Session 7

CubeSat Networks and Constellations

Highly Integrated QB50 Antenna, Power and Interface System

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The QB50 Project has many challenges that need to be met in order to make the mission a success. The mass, volume and power constraints make it challenging to accommodate the required systems inside the volume of a 2U CubeSat. Furthermore, a host of interfacing requirements are imposed to ensure the satellite can interface to the payload, ground station, AIV facilities and launch campaign interface equipment. This paper provides a concept for a set of QB50 specific, highly integrated interface systems and a dedicated OBC that minimizes the volume requirements by using smart integration of existing heritage systems.

The QB50 requirements pose constraints on the internal layout of the satellite and dictate the location of the payload, ABF/RFD and battery charge equipment. Furthermore the nature of the mission makes it desirable to maximise power. This is in direct conflict with the need for interfacing, payload placement and sensor placement for the ADCS suite. Also, the mission requirements lead to the need for a capable ADCS system. All of this together provides the teams with little moving room as the volume of the satellite will be dominated by the payload, ADCS and power system.

In order to maximize the remaining volume and mass available for the teams and potentially allow volume for their own experiments, a concept for an integrated system for external interfacing, antenna deployment and side panel power generation has been created. This system, which is a combination of the flight proven ISIS antenna system, solar panels and generic interface system, requires minimal real estate on the satellite sides, minimizing the impact on power and ADCS sensor placement. Furthermore, the system fits over the existing COTS Gomspace EPS system in the satellite stack, making the volume impact effectively zero.

Next to this integrated, antenna/solar panel/interface system a new OBC, dedicated to QB50 and directly compatible with the QB50 payloads will be presented.

Attitude Determination and Control Subsystem for a Swarm of Nanosatellites

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In a swarm or cluster of nanosatellites many satellites can work together to perform the function of one larger, usually more expensive satellite. The payload on each satellite collects and transmits experiment data to a main satellite in the group. The attitude determination and control subsystem uses chirp spread spectrum (CSS) technology in the implementation of Nanotron Technologies. The NanoLOC TRX transceiver combines robust wireless communication and CSS technology for ranging during communication.

Chirp spread spectrum (ISO 24730-5) technique uses wideband linear frequency modulated chirp pulses to encode information. It can provide high-precision ranging between the nodes with an accuracy of up to 1 m over a distance of 100 m and above. Satellites in such a swarm can measure the link distance to their neighbours and autonomously position themselves into a formation.

NanoLOC TRX supports data communication on 2.4 GHz ISM band, a freely adjustable center frequency with three non-overlapping frequency channels. This provides multiple, physically independent networks and compatibility with existing 2.4 GHz wireless technologies. This technology provides connection data rates from 125 kbps to 2 Mbps with variable output power from -33 dBm to 0 dBm to reduce power consumption.

The on-board control subsystem for the swarm of low-cost nanosatellites is based on the high level integrated ARM-architecture system-on-chip (SoC) and includes an on-board computer with RAM and ROM memory, transceiver with omni-directional antenna. The main satellite in the swarm also includes GPS/GLONASS hybrid receiver for a common orientation of the swarm in orbit and GLOBALSTAR terminal for the communication with the ground station.

The software of the control subsystem in the on-board computer includes the operating system, basic applications with the functions of the orientation, communication with other nodes and ground station (only for the main satellite), and user application for control of payload functions. The real-time operating system includes a lot of different drivers, network components, rich API for the developers and other system components and service routines.

The payload in each nanosatellite in the swarm can include a lot of different types of sensors for the experiments and measurements in the orbit, like MEMS-sensors, magnetometers, biological and chemical equipment.

The NEE Constellation: Video Satellites for Elementary Education

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The NEE constellation is composed of two 1U polar orbiting CubeSats, the NEE-01 PEGASO and the NEE-02 KRYSAOR.

NEE-01 PEGASO will be launched by a Chinese LM2D on 25 April 2013 into a circular orbit at 650 km altitude with an inclination of 98.7º and a beta angle of 22.1º. NEE-01 PEGASO will be the first Ecuadorian satellite in orbit.

NEE-02 KRYSAOR will be launched by a Russian Dnepr in July 2013 into an elliptic orbit with a perigee of 750 km and an apogee of 900 km. The inclination will be 97.8º and the beta angle will be 17.5º.

Both satellites have been entirely designed and manufactured in Ecuador by national engineers, using domestic approaches and solutions. The satellites have on-board video cameras that will attempt real time analog TV transmission from orbit as well as digital data. All data will be received by the ground station HERMES-A in Guayaquil and automatically transferred to the Internet so that elementary schools around the country can receive the video feed and the digital data signals in real time using only a browser as the satellites are passing in range of the ground station.

The main objective of this endeavour is to expose the young people to the visual feed from Earth orbit in an attempt to inspire a new generation of engineers and to support the efforts in STEM (Science, Technology, Engineering, Mathematics) education in the country by giving them access to simple digital coding that is designed to be received over the Internet and decoded using simple to use open source programs like MMSSTV, Digital Master 780, and CWMaster. The signals will decode in questions and answers about mankind’s and the country’s space history facts. This way, the school students will learn about space history and, at the same time, develop the necessary skills and science background to decode the signals while being inspired by the views from Earth orbit.

CYGNSS – A MicroSat Constellation Mission for Measuring Winds in Hurricanes

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Our ability to predict the path of cyclones has improved over the past decade, while our ability to predict the strength of the hurricane has not. This is primarily because we are able to measure the background winds, which specify the direction of motion of the cyclone, but are not able to measure the winds within the cyclone, which specify its strength. Our lack of ability to measure the winds within the cyclone is due to the attenuation of signals by rain. The CYGNSS (Cyclone Global Navigation Satellite System) satellites will utilize GPS satellite signals that reflect off the ocean's surface to determine the roughness of the ocean, and therefore the wind speed above the ocean. These signals have little attenuation due to the heavy precipitation.

CYGNSS is a NASA funded mission (~$150M) that will consist of eight ~28 kg satellites launched into a 500 km by 35º inclination orbit on October 16, 2016. They will be deployed in pairs from a single launch vehicle over a span of about five minutes. The satellites will separate over a few days, but will re-converge many times during the 2-year nominal mission. We will discuss the deployment sequence that we will use to minimize the chance of collision after half an orbit, showing the many different complications and variables to consider when deploying in such a way. Further, we will discuss coverage statistics of our measurements and how this coverage changes over time as the satellite constellation re-converges and spreads back out. Our goal is to measure 70% of the historical storm area on any given day, which we statistically can meet on any day of the mission. We will attempt to use differential drag to modify the spacing of the satellites once they are in orbit. This can be done because the solar panels are very large, but in nominal flight have very little area facing into the ram direction. When an individual satellite is tipped by just a few degrees, the area-to-mass ratio increases dramatically, allowing more drag to be felt by the satellite. Using this method, we will develop strategies for allowing our coverage statistics to be above our threshold and decreasing the probability of conjunction over the satellite's lifetime.

Ground Stations and Communication Protocols for Small Satellite Networks and Constellations

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Small satellite missions provide valuable opportunities to access space, testing emerging technologies and economical commercial-off-the-shelf (COTS) components that may be useful in future space missions, and also provide a valuable opportunity for space research. Consequently, networks and constellations of small satellites are emerging and taking an important role in space research. These joint missions increase the temporal resolution of the data and also allow merging the data retrieved from the satellites. They are intended for Earth observation and surveillance. A good example of this type of networks is the QB50 Project.

These missions generate significant amounts of data relative to the data rates usually available on amateur frequencies in VHF/UHF. Also, the relatively short pass times over dedicated ground stations limit the amount of data that can be retrieved. For these reasons, many ground stations are needed. A solution is to use amateur ground stations.

We are proposing a solution in S-Band, GAMANET/GAMALINK, to implement an ad-hoc network in space. This presentation is an extension for satellites using conventional VHF/UHF. A protocol for small satellites to send data over VHF/UHF links is proposed, based on previous scheduling. It concerns also software to exchange data between ground stations, working in a cloud configuration. This protocol is specifically tailored for the QB50 Project and it facilitates amateur ground stations to join the network. It presents the work under development at the University of Porto and Tekever under this topic and its application to already more than 10 ground stations.

The QB50 Project

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QB50 is a network of 50 CubeSats in a string-of-pearls configuration that will be launched in 2015 into a Sun-synchronous, near-circular orbit at 380-400 km altitude, just below the orbital altitude of the ISS at the time of the launch. The 50 CubeSats will comprise about 40 atmospheric double CubeSats and about 10 double or triple CubeSats for the demonstration of innovative technologies and miniaturized science sensors. All 40 atmospheric CubeSats and most of the 10 CubeSats for In-Orbit-Demonstration (IOD CubeSats) will carry a set of standard sensors for multi-point, in-situ, long-duration measurements of key parameters and constituents in the largely unexplored lower thermosphere and ionosphere.

Due to atmospheric drag, the orbits of the CubeSats will decay and progressively lower and lower layers of the thermosphere/ionosphere will be explored without the need for on-board propulsion, perhaps down to 100 km. The lifetime of the CubeSats will be 5-8 months, depending on the level of solar activity. Due to density variations along the orbit and differences in the ballistic coefficients of the CubeSats, the separation distances between the CubeSats will change, leading eventually to a non-uniform distribution of CubeSats all the way around the Earth. The lower thermosphere/ionosphere is the least explored layer of the atmosphere. All atmospheric models, and ultimately numerous users of these models, will greatly benefit from the in-situ measurements obtained by QB50.

In view of volume, mass, power and data rate limitations it is not possible to accommodate more than one main science sensor on a 2U CubeSat. To still fly a variety of science sensors on QB50, three different sets of sensors were selected

- Ion/Neutral Mass Spectrometer from the Mullard Space Science Laboratory (this instrument can be operated in either the ion or the neutral mode),
- 2 Flux-Φ-Probes from the Technical University of Dresden (one for O, the other for O_2),
- A multi-Needle Langmuir Probe from the University of Oslo (4 probes on 4 thin booms).

These sensor sets have a mass <500 g and occupy 40-60% of the volume of a 1U CubeSat. Most CubeSats will also carry several Corner Cube Laser Reflectors. Participating CubeSat teams will receive the sensor set of their choice free of charge.

Proposals for the launch vehicle, commensurate with the QB50 mission, have been received and are presently being analysed by the QB50 Consortium Board and the European Commission. In the meantime, in order not to delay the Project, the Consortium is working with so-called overlapping loads, thereby advancing launcher interface design and CubeSat deployer accommodation strategies.

During the operational phase of QB50, 3 parallel Mission Control Centres (MCCs) will be set up at VKI, Stanford and the Northwestern Polytechnic University in China. They will display QB50 key information in real time, such as CubeSat position, CubeSat housekeeping and ‘quick-look’ science data, ground station contact and predicted time and latitude/longitude of re-entry.

In response to a ‘Call for CubeSat Proposals for QB50’, issued on 15 February 2012, proposals for 78 CubeSats were submitted by universities in 42 countries, 57 for standard atmospheric 2U CubeSats and 21 for 2U and 3U IOD CubeSats. The selection of the 50 CubeSats that will participate in QB50 is ongoing and can only be completed once the funding for the CubeSats by national space agencies and industry is firmly established.

A CubeSat Constellation for Low-Frequency Radio Astronomy

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Radio waves from extraterrestrial sources below 10 MHz are reflected back to space by the ionosphere. To observe these low-frequency radio waves the radio telescope has to be above the ionosphere, i.e. in space. Up to now, the only low-frequency radio wave observations were made by the Radio Astronomy Explorers RAE-A and RAE-B, launched in 1968 and 1973, respectively. The RAE-A and -B observations were very limited in terms of sensitivity and angular resolution. To place just one telescope in space is not sufficient. To achieve good angular resolution, which is essential for identifying the source of the radio emission, the telescope either has to be gigantic (more than a kilometre in size which is prohibitive) or an array of many telescopes has to be launched just like the large arrays of radio telescopes on the ground. The Very Large Array (VLA) in New Mexico, for example, has 27 telescopes.

HALCA (1997-2003) and Spektr-R (launched in 2011) are two modern radio telescopes in space. To achieve a good angular resolution, these two radio telescopes were/are only used in combination with ground-based radio telescopes and, because ground-based telescopes are ‘blind’ below 10 MHz, the low-frequency range is still essentially unexplored. The low-frequency range can only be explored with an array of many radio telescopes in space and this has not yet been done. In the last 25 years, the low-frequency radio community has made over 20 proposals for an array of radio telescopes in space, none of which were approved.

The early proposals assumed arrays of relatively large spacecraft resulting in a high launch mass and high mission cost. Major improvements in miniaturization of spacecraft subsystems and components were incorporated in more recent proposals, notably the SOLARA and OLFAR mission studies. SOLARA is a constellation of 20 identical 6U CubeSats in a halo orbit around the Lunar Lagrange point LL1. OLFAR is a constellation of 10 (and possibly a lot more) identical 3U CubeSats, either in a lunar orbit or a halo orbit around the Lunar Lagrange point LL2. Both concepts assume CubeSat propulsion capability, deployable solar panels and data transmission from the CubeSats directly to Earth.

An attractive alternative could be an array of 50 not necessarily identical 3U CubeSats in combination with a ‘mother spacecraft’, which would transport the CubeSats from GTO to their operational orbits, deploy the CubeSats sequentially and act as a data relay. Data transmission from the CubeSats to the mother spacecraft would be in the UHF band, deployable panels are not needed. A radio-quiet orbit around the Moon, like RAE-B, would appear as the best vantage point for making low-frequency radio wave observations. After deployment, the CubeSats would use their own propulsion systems to reach their final orbits on a spherical shell with an initial diameter of 10 km. The distances between the CubeSats need not to be precisely controlled, only precisely measured. It is sufficient to have knowledge of the baselines between each pair of CubeSats to approximately 1/10 of the observed wavelength. During the mission, the thrusters are also needed to maintain the general spherical shape of the array. In the later phase of the mission, the thrusters would also be used to increase the diameter of the sphere to about 100 km to improve the angular resolution of the array. The CubeSats would be equipped with two 6-m long dipole antennas, placed orthogonally to each other.

If the CubeSats would be provided free of charge by universities around the world, as on QB50, the cost to a funding space agency for the development of the carrier spacecraft and the deployment system, the mission operations and the management of the project could be as low as 30-40 M€ plus launch cost. The launch mass is assumed to be about 320 kg.

A CubeSat Constellation for Micro-Scale Plasma Physics in the Magnetosphere

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Magnetic reconnection is a fundamental plasma-physics process that converts magnetic energy into heat and kinetic energy of charged particles, a process which is very fundamental but still poorly understood. Magnetic reconnection occurs in all astrophysical plasma systems but can be studied in situ only in our Solar System and most efficiently in the Earth's magnetosphere.

In cosmic plasmas the field lines and the plasma are tied to one another and move together with the flow of the plasma. If magnetic fields in adjacent regions have opposite or significantly different orientations, the field lines and plasma can be coupled, with the individual field lines disconnecting from each other and then reconnecting with those in the adjacent region. When this happens, the energy stored in the magnetic fields is released as kinetic energy and heat. The disconnection and reconnection of the plasma and magnetic fields takes place in a narrow boundary layer, called the 'diffusion region'. In the Earth's magnetosphere there are two such diffusion regions, one at the dayside magnetopause, the other in the magnetotail. The core of these regions is relatively small and the location of these regions varies. Therefore, a large number of spacecraft is required to 'catch one of these regions in action'.

ESA's Cluster mission, launched in July 2000 and still operational, has the objective to explore 3-dimensional small-scale plasma structures and turbulence in the key plasma regions of the Earth's magnetosphere. NASA is now developing the Magnetospheric MultiScale (MMS) mission, planned for launch in October 2014. Just like Cluster, MMS will comprise 4 identical spacecraft in a tetrahedron configuration. The separation distances between the 4 spacecraft can be varied, from 10 km to several 100 km, considerably shorter than on Cluster. These shorter distances are required to study the microphysics of magnetic reconnection,

Four spacecraft are sufficient to distinguish between 3-dimensional spatial and temporal variations but to fully understand the small-scale plasma structures in the magnetosphere a constellation of many more spacecraft is required. In 2000/2001, NASA studied the Dynamic Response And Coupling Observatory (DRACO) mission, comprising 92 identical nanosatellites in highly elliptical orbits (3 R_E x 7-40 R_E). Neither the DRACO constellation mission nor three subsequent mission studies (ORION, HERCULES, MC) were approved by NASA.

In-situ exploration of magnetic reconnection would be a first-class science goal which can only be achieved with a large number of suitably instrumented spacecraft and CubeSats are the only low-cost option. If 50 CubeSats would be provided free of charge by universities around the world, as on QB50, the cost to a funding space agency for the development of a 'mother spacecraft' including the deployment system, the mission operations and the management of the project could be as low as 30-40 M€, plus the cost of launching a 300 kg payload into GTO. The mother spacecraft would transport the CubeSats from GTO to their operational orbits, deploy the CubeSats sequentially, fly in formation with the CubeSats and act as data relay. Ideally, the payload on each 3U CubeSat would include an ion mass spectrometer, an electric field experiment, a triaxial fluxgate magnetometer on a boom, a plasma electron analyser and energetic electron and ion analysers. The distances between the CubeSats need to be controlled, therefore, the CubeSats need to have propulsion capability. The phenomenon of magnetic reconnection needs to observed simultaneously at different scale lengths, ranging from less than 1 km to several 100 km.

Session 8

CubeSat Flight Experience, Lessons Learned

Low-resource in-situ sensors suitable for CubeSats

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Low-resource miniaturised instrumentation with a high degree of integration is a key requirement and an enabling technology for CubeSats. The Mullard Space Science Laboratory (MSSL) has an ongoing development programme aimed at highly miniaturised in-situ space sensor systems and are currently developing sensors for a number of missions. The missions include the UK's TechDemoSat, the EU's QB50 and NASA's Sunjammer. This paper will present an overview of the development programme, details of the aims of the mission and the corresponding sensors under development, the current status of the developments and a roadmap of the programme vision. A brief description of the sensors follows.

The Charged Particle Spectrometer (ChaPS) delivered for the TechDemoSat mission, due to be launched in the 3rd quarter of 2013, is an in-flight demonstration of a novel analyser geometry combining a low-energy electron and an ion analyser. The instrument design is tailored for a number of different goals, measurement of electrons in the Earth's auroral regions, cold (< 60 eV) ions in low-Earth orbit and spacecraft charging, with sensor performance and operational modes optimised for each of the goals.

The Ion and Neutral Mass Spectrometer (INMS), one of the three science sensor sets on the QB50 mission - the other two being the multi-Needle Langmuir Probe and the Flux Probe Experiment - combines the cold ion detection capabilities of the ChaPS instrument with an ionizer to deliver neutral particle detection capability. The sensor geometry has been modified to address the QB50 science requirements, sampling low mass ionised and neutral particles in the spacecraft ram direction with the instrument resolutions optimised for resolving the major constituents in the lower thermosphere.

The Solar Wind Analyser (SWAN) is a miniaturised sensor to be delivered for NASA's Sunjammer solar sail mission with an anticipated launch in late 2014/early 2015. SWAN is also based on ChaPS, with performance optimised for measurement of solar wind proton and alpha particle densities. Sunjammer is a solar sail technology demonstration mission and the key aim of SWAN is to demonstrate the ability to carry out good measurements of the solar wind with in-situ instrumentation.

On-orbit Performance of the Colorado Student Space Weather Experiment (CSSWE)

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The Colorado Student Space Weather Experiment is a 3-unit (10cm x 10cm x 30cm) CubeSat funded by the National Science Foundation and constructed at the University of Colorado (CU). The CSSWE science instrument, the Relativistic Electron and Proton Telescope integrated little experiment (REPTile), provides directional differential flux measurements of 0.5 to >3.3 MeV electrons and 9 to 40 MeV protons. Through a collaboration of 60+ multidisciplinary graduate and undergraduate students working with CU professors and engineers at the Laboratory for Atmospheric and Space Physics (LASP), CSSWE was designed, built, tested, and delivered in 3 years. On September 13, 2012, CSSWE was inserted to a 477 x 780 km, 65° orbit as a secondary payload on an Atlas V through the NASA Educational Launch of Nanosatellites (ELaNa) program.

The first successful contact with CSSWE was made within a few hours of launch. CSSWE then completed a 20-day system commissioning phase which validated the performance of the communications, power, and attitude control systems. This was immediately followed by an accelerated 24-hour REPTile commissioning period in time for a geomagnetic storm. The high-quality, low-noise science data return from REPTile is complementary to the NASA Van Allen Probes mission, which launched two weeks prior to CSSWE. On January 5, 2013, CSSWE completed 90 days of on-orbit science operations, achieving the baseline goal for full mission success.

As the CubeSat continues to operate in its extended mission phase, the CSSWE team is working to understand and validate our design with on-orbit data. The power, data, and link budgets estimated prior to launch are found to be an accurate estimate of the on-orbit performance. Satellite interior temperatures are found to remain within their design range, even during periods of multi-week long insolation. However, not all systems have behaved as expected; an on-orbit anomaly occurred ten days after science operations began. An additional innovation has included autonomous operation, enabling uplink and downlink during all 8+ CSSWE passes per day and increasing monitoring capability. This was implemented in December to accommodate the lack of student operators over the holiday break and has been exceptionally beneficial. The student-led CSSWE team has grown in experience and knowledge throughout design, build, test, delivery, launch and operations of this small satellite. An overview of the CSSWE system, on-orbit performance and lessons learned will be presented.

AAUSAT3 – a new Satellite Infrastructure

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On 25 April 2013, the 1U CubeSat AAUSAT3 was launched on a PSLV C-20 into a 98º polar orbit at an attitude of 780 km. AAUSAT3 is a student CubeSat, solely designed, built and operated by students at Satlab, Aalborg University.

AAUSAT3 is based on a totally decentralized design with no main On-Board Computer(OBC). It consists of eight subsystems all communicating by use of the – for AAUSAT3 developed – open source CubeSat Space Protocol (CSP) which runs on top of a 500 kbps CANBUS 2.0B. CSP is extended to ground over the UHF spacelink so that all applications on the ground as well as in the space segment can communicate seamlessly. All subsystems have to provide a standardized server interface for basic management and “beacon information” and, in addition to that, specific services for the subsystem. A subsystem also has the capability to act at the same time as a client. The decentralized approach and the stateless protocol system have eased integration and testing very much. AAUSAT3 comprises eight subsystems

- EPS (Electrical Power Subsystem)
- COM (telecommunications subsystem)
- FP(flight planner),
- LOG(logging system),
- AIS receiver #1
- AIS receiver #2
- ADCS # 1 (for detumbling)
- ADCS # 2 (for pointing)

All subsystems share the same login system and flight planner. Furthermore, three architectures are integrated seamlessly (8 bit avr, arm7, 16/32 bit BF537 DSP) and are easily extendable with more systems.

Experiences and Lessons Learned during the Launch and Early Orbit Phase (LEOP) of AAUSAT3

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On 25 April 2013, the 1U CubeSat AAUSAT3 was launched on a PSLV C-20 into a 98º polar orbit at an attitude of 780 km. AAUSAT3 is a student CubeSat solely developed, constructed and operated by students at Satlab, Aalborg University. In the first 17 days (up to the date of submitting the abstract) the mission has been very successful with full functionality of all subsystems, and all scientific experiments performing better than anticipated.

The Launch and Early Orbit Phase (LEOP) is the most critical phase on any mission. In the AAUSAT3 mission, LEOP lasted nearly two weeks. Lessons learned cover areas like prelaunch work, early LEOP, evaluation of handling of subsystems, telemetry, handling of a critical mission phase during day 5-7 of LEOP, ground station, link and protocol considerations and much more.

Five Years of Successful Space Education and Outreach in Estonia

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The first five years of the Estonian Student Satellite Program have resulted in the successful delivery of the ESTCube-1 nanosatellite flight model. ESTCube-1 is the flagship project of the program and also the first Estonian satellite. It is a 1U CubeSat that was launched from Kourou on 7 May 2013 into a Sun-synchronous orbit at 700 km altitude by a Vega launcher.

The Estonian Student Satellite Program was established in 2008, as a nation-wide initiative with the strategic objectives to support innovation and long-term economic growth. Focus of the activities is to popularize careers in research and technology, to provide students from all educational levels, from high-school to post-graduate, with the hands-on experiences in space technology development.

During the five years, more than 80 students from different Estonian universities have been involved in the program activities. To effectively provide problem-based learning exercises in the universities, the program activities are included in the undergraduate curricula at the University of Tartu. Already in the ESTCube-1 development phases there have been 30 undergraduate and graduate theses prepared; currently 3 doctoral dissertations will be based on the satellite mission. In addition to Estonian students, the program has grown into a full-scale international collaboration with participating students from Tartu University, Tallinn University of Technology and Estonian Flight Academy and partners from the Finnish Meteorological Institute, the University of Jyvaskyla, the University of Helsinki and the German Aerospace Center.

We present the concept, educational design, and achievements of the first five years of a continuous student satellite program in Estonia.

Lessons Learned from the Attitude Determination and Control Subsystem of ESTCube-1

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We present the lessons learned from developing, testing and operating the ESTCube-1 Attitude Determination and Control Subsystem (ADCS). It is the first ADCS on a CubeSat to perform a high rate spin up for centrifugal tether deployment. ESTCube-1 is a 1U CubeSat that was launched on 7 May 2013 into a Sun-synchronous orbit at 700 km altitude by a Vega rocket. Its main mission is to perform the first in-space Electric Solar Wind Sail (E-sail) experiment. E-sail is a concept of propellantless propulsion system which uses long, charged electrodynamic tethers and solar wind momentum to produce thrust.

The E-sail experiment on board ESTCube-1 requires the satellite to be spun up to 1 revolution per second and the spin axis must be parallel to the Earth's polar axis within an accuracy of 3º. Spinning is needed to centrifugally deploy the 10 m E-sail tether. Since the spin plane should be parallel with the Earth's magnetic field lines, the experiment will be performed over the Earth's poles. The charged tether's interaction with the ionospheric plasma will produce a similar effect to the E-sail effect in the solar wind in the interplanetary medium. Charging the tether during certain positions would allow to measure the E-sail effect with gyroscopes, because the interaction between ions and the tether will change the spin rate of the satellite.

Preparing the satellite for the experiment is a task for the ADCS. Mass, volume and power of a single unit CubeSat puts strict limits on available options. The attitude determination system uses magnetometers, gyroscopes and custom-built Sun sensors which are based on Hamamatsu S3931 position sensitive devices and have an uncertainty of 1.55º. All sensors are interfaced with the Command and Data Handling System (CDHS) microcontroller with a STM32F103 processor. Attitude estimation is performed by an Unscented Kalman Filter running on CDHS which provides input to a closed-loop spin controller. The attitude control utilises custom-built magnetic torquers whose drivers are on the Electrical Power Subsystem which controls torquers based on commands sent from CDHS.

Improving and Accelerating Small Missions through Mission Operations Software

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The main focus of CubeSat missions is the development of the on-board hardware and instruments for the experiment. However, for the mission to be successful, one also needs software for downloading experiment data and housekeeping telemetry, monitoring and archiving it, controlling antennas and radios, sending telecommands to the satellite, etc. Today, the CubeSat teams are facing many challenges regarding the mission operations software

- There are existing products, however, those were built some time ago and for rather different and much larger missions,
- The budget of small projects is limited – all the effort is needed to build the satellite and instruments which are the primary goals,
- Most freely available software is only meant for ground station control,
- Software developed by CubeSat teams is tailor-made for the needs of a specific mission and not suitable for future missions,
- Often the members of the team do not have a software engineering background and the required skills.

Finally, the teams struggle with the software each in their own corner to cover the minimum for their mission. The mission operations software is usually far from what it could be from a user point of view. It is especially remarkable as all teams need almost the same functionality, and often the underlying hardware and low-level communication protocols are very similar.

A few years ago, CGI employees, working daily on complex and mature mission control systems, started an open source initiative called Hummingbird. One of the motivations was to make use of the modern software development tools which could significantly reduce development costs and, at the same time, offer much more flexibility and usability for the end user. Today, Hummingbird is a good baseline for small missions having implemented the core modules of transport layer, telemetry encoding and decoding mechanisms, etc. ESTCube-1 is the first mission using Hummingbird as a backbone for their web-based mission control system, and CGI has supported this activity with its knowledge and experience. At the same time, several other teams have expressed an interest in this work for the reasons given above.

Creating a ready to use but flexible solution with minimal customization effort on top of Hummingbird for CubeSats would be a small investment but could save a lot of time, money and stress for many missions worldwide

- The teams can focus on their primary goal – building the satellite and payload instruments – increasing therefore significantly the success rate. What is finally sent to space is of high quality and has been tested properly and sufficiently on ground.
- The communication principles and software has been tested on multiple missions. This will ensure that there are no surprises in controlling the satellite or downloading the data.
- Using heterogeneous software built with modern tools will greatly improve the ability for the missions to integrate with a minimum effort. For instance, it would allow easy sharing of ground stations between the satellites which would increase collaboration between CubeSat teams.
- Having a sophisticated solution simplifies and reduces the work of the operator greatly, and the integrity of the downloaded data and its archiving is trustful.

Lessons Learned in the PW-Sat Project

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The CubeSat standard is getting more and more popular in the world. In next few years, the number of CubeSats built and launched for educational, scientific and technological purposes will reach 100, and perhaps even more. Many thousands of students are involved in the development and operational phases of these projects.

PW-Sat was launched on 13 February 2012 on the Vega Maiden Flight as the first Polish satellite. Experiences and knowledge gained in this project as well as other CubeSats launched on the same launcher led to this complete lessons learned summary.

The example of the PW-Sat Project gives a list of issues related to software, hardware as well management which provides useful guidelines for any CubeSat project, especially when the CubeSat is the first CubeSat within their institution or country. The topic of lessons learned can be split into sections which cover the following parts

- Project management,
- System engineering,
- Mission design,
- Satellite development process,
- Post-launch operations.

The example of PW-Sat gives a comprehensive analysis of issues met during all project phases, for example, lack of automatic modes which caused a problem with meeting the mission goals, a test campaign which was too short and influenced the power budget, and so on. As a result, PW-Sat, which was intended to test a new de-orbiting system based on a drag augmentation device, could not reach all mission success levels.

The analysis of a 'lessons learned' exercise performed by the PW-Sat team implicated a need to provide guidelines for our next satellite project, the PW-Sat 2. PW-Sat 2 is intended to be 2U CubeSat, equipped with more devices and payloads than the first one, for example, a sail to de-orbit the satellite, and a new type of the Sun sensor which has never been tested in space. It also forces the definition of requirements at any level of the project to avoid circumstances which could be predicted as well as to minimize the risk of failure during the mission. These lessons can be shared with those organizations and institutions which are going to develop their first CubeSats, and to help them to reach their mission goals.

Rapid Development of On-Board Software with Software Components

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Increasingly, CubeSats are a means to an end. Whereas in educational CubeSat projects run by space engineering departments in universities it may still be desirable to produce hardware and software 'from scratch', many users just want to fly their payload as quickly and economically as possible. For the latter group, the value of the mission comes from the successful operation of a payload over an extended period of time, whereas for the former it is largely from the experience of developing a spacecraft, regardless of how long or how productively it operates. Developers in the second category find their job greatly simplified by the availability of proven off-the-shelf hardware subsystems from a range of vendors. In contrast, when it comes to providing software, they are invariably faced with the prospect of writing their own. At best this is an unwelcome distraction, at worst a major source of schedule, financial and technical risk.

In this paper we present an alternative; rapidly assembling software from a library of proven components. We describe a portable component-based software framework which provides an environment in which platform-independent components may be deployed. These components provide common functionality such as data pooling, logging and telemetry monitoring. The developer is thus freed to focus on providing only the functionality unique to their mission. In this they are assisted by a code-generation tool which will create a skeleton component based on an XML model of its interface. Additional tools automate the creation of the spacecraft database used to define the space-ground interface.

We describe our experience of using this architecture for the UKube-1 on-board software and discuss the prospects for further automating the production of on-board software.

Design of a Flight Software Framework of CubeSats Supporting a Multi-Layer Operating System (OS)

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In recent years, interest in CubeSats has rapidly increased in governments, universities and research institutes because CubeSats can do a variety of missions at low cost and within a short development time. Already over 100 CubeSats have been successfully launched in the world for scientific purposes and as test beds for innovative technologies.

For accelerating CubeSat technologies, the role of the flight software is very important for decreasing the size and mass of a CubeSat. But, when developing flight software for CubeSats, the engineers must know each part of the hardware and software in considerable detail. We call this sort of development way in-house development. But, in order to reduce cost and development time for CubeSats, we need a more elegant development way.

For this, we are now focusing on making and standardizing common flight software for CubeSats. In this paper, we propose a flight software framework of CubeSats supporting a multi-layer operating system and describe the design of this framework. As a first step, we are now considering the Salvo FreeRTOS (Real-Time Operating System) that is usually used in CubeSats as our supporting operating system. This framework has a multi-layered structure, such as CubeSat flight software driver layer, CubeSat flight software core layer, and CubeSat flight software service layer.

Because it is platform independent, engineers such as flight software developers can write flight software services very easily on various platforms. This framework can be used very easily with high software quality for various applications, such as a constellation. Also, we can describe the first step of how to develop CubeSat flight software. We think our endeavor will make a nice environment for developing flight software of CubeSats more easily and quickly.

QBito EPS and Structure as Technology Demonstrators for Students

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QBito is one of the 40 selected CubeSats that will form a network of 2U CubeSats, separated by a few hundred kilometres, which will carry identical sensors for in-situ measurements in the lower thermosphere and ionosphere (90-380 km altitude). The E-USOC team at UPM is in charge of the design, manufacture and assembly of this 2U CubeSat.

Apart from its scientific interest, one of the more relevant aspects of the QB50 program is the freedom that the teams have for implementing the architecture of the CubeSat. This feature makes this project extremely interesting for universities because it allows integrating students and senior engineers in the development of a spacecraft that participates in a well-defined mission with a set of detailed requirements and fixed schedules. However, it is not easy to accommodate the particularities of students and professors within the tight framework of a space project. In addition, the development of such kind of projects in the university normally is accompanied by low funds and human resources which introduces an extra risk factor. Both are severe constraints that limit the challenges that this kind of teams can assume.

In this presentation, the main decisions adopted by the E-USOC team to balance the participation of young students in new developments, which increases the uncertainty associated to the project success, with the use of well-known and well-established technologies, which decreases the probability of failure, are discussed.

The main questions to be addressed are: how can CubeSats be designed so that they can be used as technology demonstrators for students in the academic field? What are the best subsystems for this purpose? In this communication we explore the approach made in QBito as follows. Firstly, the relationship between the CubeSat layout adopted for QBito and the mass, power and data budgets are discussed. Secondly, the selection of the 'built-in-house subsystems' is discussed. The subsystems selected for being developed by the E-USOC team from the conceptual design stage to the flight model are the structure and the Electrical Power Subsystem (EPS). Thirdly, the main characteristics adopted for these subsystems are presented.

Nanosatellite Myths versus Facts

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Spacecialist, Hod HaSharon, Israel

Since the debut of CubeSats, only a decade ago, they were considered by traditional space industry as "nice to have", "educational tools" and "toys". Even though companies like Boeing, TAS, Astrium EADS (SSTL) and IAI initiated nanosatellite departments and projects, they all still treat COTS-based CubeSats as not serious enough.

Nanosatellites and CubeSats developed at an amazing rate, and in less than ten years, we can now say we are at the verge of the third generation in CubeSat evolution.

After the first generation (1999-2008) being acting as the modern age Sputniks, and second generation (2008-2012) dedicated to development of subsystems and 3U platforms, the third generation (2013-2015?) will present much more power, robust and accurate attitude control systems and, finally, propulsion.

There are a lot of myths and rumours regarding nanosatellites' success rates, reliability and maturity. This is mainly due to biased and manipulative use of failure statistics.

This presentation investigates three major myths for CubeSats, being

1. CubeSat reliability,
2. COTS components reliability,
3. Mission lifetime,

and checks weather the general notion related to CubeSats is based on myths or facts.

Session 9

Future Technologies on CubeSats

The NANOSAT FP7 Project – Nanosatellites beyond 2013

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NANOSAT is a FP7 project with the title **"**NANOSAT- *Utilizing the potential of NANOSATellites for the implementation of European Space Policy and space innovation".* NANOSAT aims at contributing to a roadmap for space and innovation in Europe through studies and events in support of highly capable small satellites and thereby innovative space applications and new business models for space missions in Europe. In order to reach the desired impact, the NANOSAT project will

- create opportunities for continuous collaboration among nanosatellite developers,
- further the advancement of a nanosatellite platform,
- speed up development of innovative space applications and share the best practices in the nanosatellite community,
- consolidate the main actors in the European nanosatellite community by creating a functional network, showcasing best practices and potential markets, thereby serving the objectives of the European Space Policy,
- demonstrate the potential of nanosatellites in Europe by proposing innovative services, which will complement and create synergy with GMES services by addressing information needs faster and more flexibly.

The first part of the work has been a web survey conducted by NANOSAT where over 400 nanosat/CubeSat people around the world have been invited to participate. The purpose of the survey is to investigate which direction(s) the nanosat/CubeSat technology and people will be heading in the coming years. This includes technology, science, education, etc.. Preliminary results will be presented along with our roadmap for the project.

OPS-SAT, an ESA 3U CubeSat for accelerating innovation in satellite control

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This paper describes the current status of the OPS-SAT project. OPS-SAT is designed to demonstrate ground-breaking satellite and ground control software under real flight conditions. This is needed because critical software is generally selected for its proven, rock-solid reliability rather than its use of the latest and newest programming technologies. For example, ESA is still using the Packet Utilisation Standard to control our satellites, which was defined in 1994. Quite simply, no one wants to use new and possibly problematic software on a multi-million-euro mission in space.

OPS-SAT intends to change this. It has an innovative design which means the satellite is easily recoverable from the effects of 'buggy' software. It also uses CubeSat COTS parts wherever possible to keep the cost under control. Therefore, much more risk can be taken when performing experiments. On the other hand commercial, off-the-shelf processors provide increased computing power compared to normal ESA spacecraft. This allows OPS-SAT to fly modern software like Linux and Java and so experimenters can employ newer techniques, protocols and skills to push the boundaries in spacecraft control. OPS-SAT also has very high uplink and downlink data rates compared to university CubeSats (Mbps compared to kbps) meaning that software can be changed quickly and often. Depending on the available on-board resources the project is also considering carrying an innovative X-band transmitter being developed by CNES. This would be able to achieve a downlink data rate of up to 50 Mbps.

The project kicked off with a very successful ESA Concurrent Design Facility (CDF) study early in 2012. Consultation with industry and other European institutions (GSOC, CNES, etc.) resulted in a series of design changes, the most important being the incorporation of an on-board reconfigurable FPGA. The project attained the backing of the Austrian, Danish and German ESA delegations and so was able to move to Phase AB1 at the start of 2013. At the same time, ESA opened a Call for Ideas for OPS-SAT experiments across Europe. The response from European industry and academia has been overwhelming. Over 90 experiments have been shortlisted to be considered in the Phase AB1 mission requirements. OPS-SAT is planned for launch in 2016. ESOC mission analysis has calculated that it must be launched into an orbit with an altitude of 640 km or lower to be compliant with the 25 year rule on re-entry.

X-band Downlink Capability for CubeSats

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In 2012, Syrlinks started to deliver a new X-band High Data Rate TM transmitter for microsatellites. This development has been done under CNES and ESA contracts. The first FM (2 with AsGa RF PAs and 1 with GaN RF PA) have been delivered to ESA for the Proba-V microsatellite now launched.

Based on this know-how, Syrlinks had been developing for CNES since 2011 a new solution to download payload telemetry in X-band for smaller platforms such as nanosatellites and CubeSats. This promising solution should increase the range of missions that may benefit from these kinds of platforms. Last year a demonstration of X-band subsystem feasibility for a very small platform has been presented by CNES, with some key dimensioning performances and preliminary specifications of the transmitter and the antenna.

This paper starts with a reminder of the main performances of the transmitter which is able to modulate data up to 100 Mbps and to deliver 2 W of output power with no more than 10 W DC/DC consumption. It can be accommodated within a volume of only 0.3 U of a CubeSat. A specific focus will be on the Variable Bit Rate (VBR) option which allows optimizing the capacity of the downlink with the link budget.

VBR operations are proposed to be tested in the ESA/ESOC 3U CubeSat OPS-SAT. OPS-SAT is designed to demonstrate ground-breaking satellite and ground control concepts under real flight conditions. The project kicked off with a very successful ESA Concurrent Design Facility (CDF) study early in 2012, in consultation with European industry and other European institutions (GSOC, CNES, etc.). The design resulting from this CDF study includes the X-band microHDR-TM to perform the experiment called "*New X-band telemetry operation concepts for small sats and small class Ground Stations*". Thanks to the new concept of CCSDS compatible Variable Bit Rate, assuming conservatively a zenithal data rate of 50 Mbps, with 3 passes per day, a volume of 17.4 Gb can be downloaded with a 3.4 m station and 39.9 Gb with a 5 m station.

Then, the architecture of the transmitter is presented with all the key functions such as the power amplifier, synthesizer, IQ modulator, filters. Some results achieved on the prototype are presented with particular attention to the DC/DC consumption versus RF output power, BER measurements and transmitter quality losses. The process used to select and qualify the key components is also described. Moreover, the paper describes the achieved development and realization of a prototype with all the RF and BB functions. The prototype is mechanically and electrically well advanced, thanks to the heritage of the PROBA-V transmitter. For the prototype, input digital data (LVDS) have to be encoded with a convolutive coder. A RS422 housekeeping link is also used. The final digital interfaces for the flight models are not yet finalized, but they should be the most convenient ones for the majority of CubeSat manufactures.

Satellite ID Tag

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For CubeSats networks and constellations it is often important to know the orbit and relative position of the satellites with high accuracy. A high precision GPS can provide this data, but may be prohibitively resource-intensive for a CubeSat. An alternative solution is radar, however when the satellites are in close proximity it is often not possible to distinguish between them.

CubeSat designers and mission planners need a system that is low cost, low power and has a very small volume, as well as being simple, reliable and independent of other spacecraft subsystems, and easy to operate.

Such a system, called the Satellite ID Tag (SIDT), has been developed by a team in South Africa and Australia. It uses ground-based laser ranging systems to determine the precise location, while returning an identity code unique to the spacecraft. It is comprised of one or more modulated Corner Cube Reflectors (CCR) mounted on the CubeSat body coupled with laser ranging and demodulator systems at a network of laser ranging ground stations such as the one operated by EOS systems at Mt. Stromlo, in Canberra, Australia. When illuminated by the ranging laser the CCRs “squawk” a unique ID code back to the ground station by modulating the reflected beam, thereby offering functionality analogous to a radar transponder. The ground station then extracts the ID code and performs high precision orbit determination to enable delivery of the satellite orbital parameters over the internet.

Using the capabilities of Mt. Stromlo as an example, the SIDT can offer an orbital solution of accuracy from ranging a few m up to 1 cm using modulated CCRs with a volume footprint of 10x10x20 mm and a power draw less than 20 mW. As the typical beam divergence and telescope pointing accuracy of the Mt. Stromlo ranging lasers is 6 and 1.4 arcsec respectively, the SDIT system also possesses inherently high discrimination. Collectively, these properties make SIDT particularly suitable for the high-precision tracking of CubeSats deployed in swarms, such as those in the QB50 network.

Electric Solar Wind Sail Propulsion Outside the Magnetosphere on Board a CubeSat

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The electric solar wind sail (E-sail) is a novel, potentially the fastest and most economical interplanetary propulsion system for spacecraft. It is a propellantless propulsion method based on the interaction between charged tethers and the natural solar wind or other plasma streams.

The first satellite mission with the E-sail technology on board is ESTCube-1 which tests it in low-Earth orbit where a 10 m charged thin metallic tether interacts with the ionospheric plasma ram flow instead of the solar wind.

Here we consider the next step mission which is to take the experiment outside the Earth´s magnetosphere and into the solar wind environment for the first time. The working name for the mission is SWESTCube, Solar Wind Electric Sail Testing CubeSat.

The mission uses an innovative MEMS-based cold gas micropropulsion thruster for reaching its final orbit. The MEMS thruster is developed for nanosatellites which cannot use the typical thruster systems due to limitations of mass and volume.

According to preliminary study results, a 3 to 6 unit CubeSat would be launched into GTO and propelled to an apogee altitude of 150,000 km by the cold gas thruster. Then the satellite will spin and deploy four ~150 m long 25–50 µm thick tethers, charge them to ~+10 kV and measure the resulting ~0.1 mN E-sail force by up to three complementary methods: optical tether deflection, direct accelerometer measurement and orbit determination.

This mission would send the satellite up to altitudes that no previous CubeSat has reached so far. The technologies to be tested propose new ways of space transport, both for small satellites orbiting the Earth and for fast interplanetary travel.

The satellite is being developed in partnership with universities, institutes and private partners from Estonia, Sweden, Finland, Latvia and Slovenia.

A Free-Return CubeSat Mission to Prepare the Human Exploration of Mars

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In order to prepare a human mission to Mars, a few aspects of the mission still have to be investigated. These aspects include the dose of radiations that the crew will have to withstand during the mission, as well as the meteoroids environment around the spacecraft during the Earth-Mars transfer, at Mars and back to Earth.

Fortunately, there is a relatively cheap and easy way to improve this knowledge: using a CubeSat to study the radiation levels as well as the meteoroids environment during the cruise, around Mars and its moons, and back via a trajectory close to Venus' orbit. The CubeSat would carry a dosimeter for radiation measurements as well as a radar, inspired from a planetary altimeter, to define the surrounding meteoroids environment during its mission.

The CubeSat would use an Earth-Mars free-return trajectory that leaves Earth, fly by Mars and return to Earth without any deterministic maneuver after trans-Mars injection. This trajectory will be most likely the one used for a human mission to Mars and would allow a CubeSat mission to Mars to be feasible. The duration of the mission would be approximately 500 days.

The major challenges which usually appear when designing a CubeSat mission for Solar System exploration, like the propulsion and the communications, could be overcome in this particular mission. In fact, the CubeSat would acquire data on its way to Mars and on its way back to Earth and would then transmit them to a Martian orbiter while approaching Mars and to a ground station on its way back to Earth. Also, after trans-Mars injection, only small corrections of the trajectory are needed, making the mission possible by using a micropropulsion system on board the CubeSat.

Such free-return trajectory opportunities will occur in 2015 and 2018. At the current stage of the project, payloads of the CubeSat are being dimensioned and a preliminary mission profile is being designed.

Alternative Image Compression for CubeSats

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This paper discusses the design of an alternative image processing system for CubeSats, based on automatic Region of Interest (ROI) detection and image compression techniques. The limitations of bandwidth, transmission power and storage on board are significant constraints on the development of a CubeSat's capabilities. Many CubeSats used for Earth observation produce large amounts of data and thus there is an increasing need for larger storage space and faster download rates that cannot be achieved with the limited resources available on a CubeSat. In this paper, methods to decrease the size of CubeSat images on board, which will lead to a decrease in the data rate and power transmission, are discussed.

The proposed algorithm consists of ROI automatic detection and an image compression module. The ROI is a technique that defines the area of an image that contains useful information. The implementation of ROI automatic detection has been studied using edge, histogram and texture segmentation techniques. After these have been applied, morphological techniques using structural elements have been used to connect areas and identify the ROI. This enables the size of the original image to be reduced by discarding the unnecessary parts in the image. The image compression module implements the image compression recommendation of the CCSDS, based on the discrete wavelet transform. The proposed system performs the ROI automatic detection first, then the data passes to the image compression module. The appropriate microprocessor implementation is dependent on the mission requirements. In the implementation of the proposed system on a CubeSat, additional power would be required for this processing and it is important to verify that this increased power does not outweigh the benefit of reducing the data that has to be stored and transmitted. To quantify this increase, a particular automatic ROI detection and image compression process has been studied. By evaluating the number of computer instructions required the power usage in hardware that could be used on a CubeSat has been assessed. The size and shape of the morphological structure element used has been found to affect the output image size and power consumption. This has been investigated in this paper to find the most appropriate type for the proposed system.

The results show that the proposed system using the alternative image compression processing is able to reduce the size of the image and decrease the data transmission rate, using techniques that could be implemented on a CubeSat. The power requirements have been quantified.

High-Resolution Images Obtained by 'Computational Imaging'

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The technology, utilizing CubeSats as platforms for carrying an optical camera, is an important supplement to other remote-sensing systems that are employed in the field of environment monitoring from space. Traditional imaging systems, constrained by the requirements of miniaturization and low-mass imaging devices, obtain images of low spatial resolution and with blur. To avoid the constraints on the mass, power, aperture diameter and size of photo-sensitive cells imposed by the CubeSat platform, an innovative 'computational imaging' method is proposed, in which data measuring approaches based on spatial-temporal compressed sensing are introduced to form a new high-resolution imaging method. This method is of significant importance since it reduces the dependence on imaging hardware, improves sensing cells' spatial resolution to obtain clear images, and provides supportive technology for obtaining information from space.

The basic idea of the proposed method is as follows: first, analyze the physical features of the measuring matrix (the design of MASK matrix), combining with stochastic deconvolution to realize the stochastic and parallel measuring on the imaging target to gain the parallel coding on the target image, end up with improving the efficiency as well as maintaining the spatial distribution information of the measured targets; then, model the image restoration problem as a joint optimization problem by introducing the prior obtained by measuring the design of the MASK matrix; finally, reconstruct high resolution image by numerical calculation.

Phase Change Material for CubeSat Thermal Management

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On board a satellite, the experiments and subsystems have to be maintained within specified temperature limits. Phase Change Materials (PCM) offer the possibility to store thermal energy directly as latent heat of fusion. In the frame of a recent ESA study, a prototype has shown that the temperature range of sensitive equipment could be drastically reduced. This advantage will furthermore be increased as the thermal inertia of the spacecraft becomes very limited. CubeSats are therefore very good candidates for Phase Change Materials, which absorb transient dissipation and avoid jeopardizing the mass. Fields of application are numerous, such as maintaining batteries within their operational temperature range or damping energy dissipated by microthrusters. A new ESA study is on its way to enable TRL6 to be shortly reached and open up flight qualification. A technical demonstration is presently developed for QB50 in collaboration with the University of Madrid.

Innovative Low-Cost Thermal Components for CubeSats

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Until now, due to limited size and low power consumption, a thermal control design is hardly needed for CubeSats. However, with increasing complexity, size and power consumption of CubeSats, the need for thermal stability assessments and low-cost thermal components increases.

Future thermal components are foreseen for:

- payload cooling,
- battery heat management,
- support for the increase of power generation,
- support for the extension of overall lifetime.

Selection criteria for such thermal components for CubeSats are commercial availability, suitability for use in a space environment, low mass, small volume and low power consumption.

As part of NLR's internally funded research projects, thermal components are identified, further analysed and tested using in-house thermal test facilities.

The National Aerospace Laboratory NLR is the central institute for aerospace research in the Netherlands. Its principal mission is to render scientific support and technical assistance on a non-profit basis to Dutch and foreign aerospace industries and organisations, civil and military aircraft operators and governmental agencies concerned with aviation and space flight. The main focus of NLR's thermal group within the Space Systems Department is on one- and two-phase cooling systems. The group also has very broad experience and knowledge regarding thermal modelling and development of innovative thermal hardware ranging from advanced coatings, multi-layer insulation, phase change materials, Peltier, thermal switches, (loop) heat pipes and pumped loops.

PICARD, an On-Board Computer for Future CubeSat Missions

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PICARD project (PIcosatellite Computer ARchitecture Development) is concerned with building an on-board computer for future CubeSat missions. It aims at building a safe, highly-available system which enables satellite management, high performance processing of payload data and consuming low power.

The computer utilizes a microcontroller and a low-power SRAM FPGA. In the first laboratory model an ATmega128 microcontroller is used to manage the whole computer. It has low performance, but also low power consumption and, according to the 2010 IEEE Radiation Effects Data Workshop proceedings, has radiation parameters acceptable for low-Earth orbit. For improvement of its reliability, few software fault tolerant techniques are tested in order to apply in processor program. The main reason for using a FPGA is to achieve high performance in mass, parallel computations. Although SRAM FPGA configuration data is sensitive to radiation effects, there are many mitigation techniques possible to apply in systems utilizing FPGAs (e.g. double/triple modular redundancy of functional blocks, configuration errors checking by CRC sums, error scrubbing). A reconfigurable FPGA gives the opportunity to adapt to different communication interfaces of satellite subsystems, therefore facilitating the satellite design phase, and enables reconfiguration of processing cores during the satellite's mission.

Communication interfaces used in OBC, include links typically utilized in CubeSats: I2C, UART, CAN, as well as serial gigabit links for fast communication with the satellite's radio subsystem and payload. To connect to other satellite boards, a 104-pin connector is used (pinout as in typical CubeSat boards), together with FMC LPC 160-pin connector for faster data transmission. On-board memory consists of SRAM, DRAM and flash chips (NAND flash for payload data storage and NOR flash working in triple redundancy to store FPGA configuration data). Furthermore, new types of memory, PCM and MRAM, are installed in the computer, in order to test their behaviour in radiation environment. To minimize power consumption, a small microcontroller is used as a primary processing unit. Flexible control of power draw is possible when the computer tasks are divided up into different functional blocks of the FPGA. A block which is not used can be switched off to save energy. Software-defined-radio module with gigabit communication links is an example of such a block: it should work only during the satellite's pass over a ground station. In order to improve reliability of the computer, the current draw is monitored The current is cut off if it is too high (latch-up protection). Watchdogs and coupled watchdogs are applied to recover from functional interrupts and in most sensitive points of design, an analogue voting mechanism is used.

The Open Prototype for Educational NanoSats

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This paper presents a technical overview of the mechanical, electrical and software design of the Open Prototype for Educational NanoSats (OPEN). OPEN is designed to reduce the cost of CubeSat development at institutions world-wide by making it so that a CubeSat can be developed with a parts budget of approximately $5,000 (excluding the mission-specific payload). The OPEN initiative will make the technical documents (CAD diagrams, PCB diagrams, fabrication instructions, testing plan, etc.) and operating software available freely online, facilitating their use by CubeSat programs.

The OPEN configuration implements a non-conventional design where four PCBs are mounted vertically surrounding an open payload area (5 cm x 5 cm x 10 cm) in the center of the spacecraft. Because of this configuration, the boards are able to access the 0.6 cm overhang space between the 10 cm x 10 cm slide rail dimensions and the interior of the PPOD. This allows the use of approximately 30% more volume, as compared to the typical 10 cm x 10 cm x 10 cm dimensions.

This configuration also minimizes the amount of mass and volume devoted to an aluminum structure, as the PCBs are utilized as part of the structure (removing the need for aluminum cross-braces or a solid aluminum side panel). The configuration also allows each board (e.g., the communications board or payload board) to directly deploy board-connected components to the exterior of the spacecraft or to mount an exterior-facing camera (e.g., for a star tracker). The centrally-located payload area facilitates the use of an optical system whose focal length can be maximized relative to the dimensions of the spacecraft or the placement of a propellant tank at the spacecraft’s center of mass.

The base OPEN configuration will include all standard spacecraft subsystems, excluding propulsion. It will feature a sample imaging payload. A brief overview of each subsystem is provided with particular focus provided to the sensors and bus, communications, power generation and attitude determination and control subsystems.

Session 10

CubeSat Deployers

S2S-CAM, an autonomous camera system with near real-time image delivery capability

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Real-time images from small digital cameras are used today in several electronic devices like smartphones, desktop computers, laptops, and tablet computers. In contrast, small digital cameras on satellites are typically used for Earth imaging or as sensors like star cameras for attitude control. Some missions, like the Rubin satellites and payloads from OHB System, SNAP from SSTL and the two Swedish Prisma satellites flying in formation, have used cameras for deployment monitoring from either the launch vehicle or other satellites or simply for taking images for PR purposes.

This paper describes such a monitoring camera system as an autonomous unit with the capability to deliver the images from anywhere in LEO within a few seconds, i.e. close to real time. This is possible by using commercial satellite networks. The images are delivered to the end user by a web application which runs on any modern smartphone or computer. The camera system will automatically record the satellite deployment sequence from the launch vehicle and additionally send telemetry data like the GPS position and the time. Integrated Sun sensor and magnetometer measurements deliver also the estimated launch vehicle upper stage orientation and rotation rates during the satellite deployment.

The autonomous camera system will have its own, launch vehicle independent, small power subsystem consisting of a few solar cells and a small battery. High quality video and pictures can be delivered via an additional direct S-band downlink channel to the ground stations in Latvia, Germany and Italy. The mass of the camera system, including a few cameras, electronics and power supply, excluding the telecommunications subsystem, is estimated to be about 300 g.

As an example, in the QB50 mission, a camera system comprising multiple wired or wireless cameras could be used to image the deployment of several CubeSats from a single deployment system from different angles and locations. Several such camera systems would be needed to image the CubeSat deployments from several deployment systems distributed in the payload volume of the Cyclone-4. The camera systems would be a stand-alone subsystem mounted on the outside of the deployment systems.

Another example could be an additional camera payload on ESOC's planned 3U OPS-SAT CubeSat.

Occasionally, the deployment does not go as planned and a CubeSat can get stuck in the deployer. This is what possibly happened, for example, to the Norwegian Ncube II during the deployment from SSETI Express on 27 October 2005. There was no camera system imaging the deployment and what exactly happened is up to speculation.

The S2S-CAM could be utilized for many future missions where real-time images and information will dramatically increase the public awareness without compromising the mission goals. Satellites or launchers could take the opportunity to provide their customers or the public with real-time images taken by the S2S-CAM. Furthermore, the images obtained by the camera system could provide extremely useful information for the failure analysis if something goes wrong with the deployment.

Posters

Mechanical Design for an Open Hardware Spacecraft

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The Open Prototype for Educational NanoSats (OPEN) initiative is creating designs which can be utilized to build a low-cost CubeSat. Educational and research teams from around the world can use these design documents which are freely available online from OPEN to decrease design time and cost.

The structure OPEN implements is different from most CubeSats as it makes use of an area of space between the wall and frame rails in the PPOD deployer, called the overhang space. This space can be used to accommodate non components, such as those for payload or a propulsion system for the CubeSat.

This design has a simple physical approach: the electrical boards are inserted vertically and are supported by a corner-post frame. While the physical configuration of the boards is different due to the incorporation of electrical stacking without physical stacking, their function is still the same. Structural stability is also enhanced by the boards in addition to the rigidity from this corner-post base plate frame. Doing this allows 30% more volume in the spacecraft than in a standard 10x10x11 cm^3 CubeSat configuration that does not take advantage of the overhang space. Many iterations using computer-aided modeling software helped refine the structure. The idea of vertically mounted electrical boards helped spark some of the earliest design models. Those early models also helped guide subsystem positioning and design, so that they took advantage of the overhang space. As revisions were made, the designs of the configuration of the subsystems became more specific. The latest and most detailed model is presented in this paper which includes a single assembly with finalized sections of the structure.

The paper also presents the process that was used to design the structure along with the successes and failures that occurred while getting to this point. Concluding this paper, the next steps toward completing the OpenOrbiter CubeSat are discussed.

Design and Development of Software for Camera Operations and Image Processing on board OpenOrbiter

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Software for camera operations and image processing is required for taking images from a camera on board OpenOrbiter and manipulating them. This manipulation could include compression, mosaicking, performing super resolution, or any combination of the three.

The ground station sends up information to the operating system regarding what to take pictures of and what to do with those pictures. The operating software provides this information to the payload software which determines when to take the pictures. The operating system then waits until the appropriate time, takes the pictures, wakes up the payload computer, and sends the pictures to the image processing software. These messages are sent through TCP/IP. The image processing software receives the pictures and performs the requested tasks.

The ground station could, for example, send up a request for pictures at certain coordinates and requests for them to be mosaicked together. The operating software then takes the pictures and sends the pictures to the image processing software which then mosaics them into one combined image. The method used to perform this mosaicking is an open version of SIFT (Scale-Invariant Feature Transform), called openSIFT. OpenSIFT looks at all the pixels in an image and detects key features by using the surrounding pixels and places a vector accordingly. These features are matched with corresponding features in other pictures which allows the images to be combined into a mosaicked picture.

Super resolution is similar to this except that instead of overlapping the images to make a bigger one, the overlapping regions are selected. These areas are then broken up into pixel grids and combined programmatically into a higher resolution image. For instance, four pictures are taken and are going to be super resolved. The images are run through the openSIFT software to identify overlapping areas which are then taken and broken up into grids. The juxtaposition of the images yields pixel values for each position. This creates a new set of pixels for an image that is four times the size of the original overlapping area. The pixels are all matched up to how they were in the original overlapping image and a final picture is made.

Mosaicking is performed before super resolution, if both services are requested. Once this is done, the picture can be compressed using a lossless compression method. Once compressed, the payload software sends a message back to the operating software saying that the task is complete along with an identifier for the picture that was processed for later retrieval by the operating software.

This poster describes in detail the operating and image processing software and its design and development. It also presents the future work required to achieve a point where it can be used by other groups as it is, or modified to work in a different spacecraft or mission. OpenOrbiter is fundamentally an enabler for others: what is done today can be utilized down the road and changed to fit the needs of other groups.

Anant, a Small Satellite Initiative at NIT Calicut

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An attempt is being made to initiate a small satellite project at NIT Calicut, named Anant. The objective of Anant is the investigation of the ionosphere by making magnetic field measurements from 1 to 20 Hz at an altitude between 550 and 650 km. The orbit chosen for this mission is Sun-synchronous. These measurements will be used to study the Earth’s inner space environment, the ionosphere and related electrodynamics.

A comparative study has been done on the design aspect of a search coil sensor and a fluxgate sensor and their feasibility as payload on a small satellite. The study came to the conclusion that the LEMI-011 three-axis fluxgate magnetometer was the most suitable sensor. The magnetometer sensor has to be mounted on a deployable boom to keep it away from the spacecraft's residual fields. Various designs of deployable booms have been studied in detail that would best suit a small satellite.

The paper describes the science behind this small satellite mission with a magnetometer as payload, its educational goals, the requirements for the various subsystems, and the technological challenges to realize this mission.

The paper also discusses the various ground-based techniques to study geomagnetic phenomena and the role of satellites in these studies. The current status of student satellites under development by various universities in India will also be discussed.

A simple, inexpensive CubeSat instrument for in-situ measurements of orbital atomic oxygen flux

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Atomic oxygen (AO) is the predominant and most active component of the neutral atmosphere at low-Earth orbital (LEO) altitudes. It can bring serious influence on the LEO spacecraft which would jeopardize on-orbit safety of spacecraft and accomplishment of the missions. Therefore, the study of AO effects is very important for the high reliability and longevity of spacecraft.

In the present work, the silver film resistance method for AO flux measurement has been studied and the silver-based sensor for space flight test on board a small satellite has been designed for its small size, low weight, low power consumption, low cost and easy construction. The total mass of the AO sensor is about 60 g, peak power consumption is less than 0.2 W.

The AO sensor was composed of two parts: the detector unit and the measurement unit. The detector unit which was manufactured by sintering pure silver on alumina ceramics substrate to form a silver film layer was mounted outside the satellite to react with AO. The measurement unit inside the satellite was used to power the detector unit and output voltages representing the silver film resistance. This AO sensor was first calibrated on ground by comparing it with the Kapton film mass loss method. Then it was launched into orbit on board the nanosatellite "Space Pioneer 1" to measure the AO flux at the orbital altitude of 476 km. The measured AO flux was compared critically with theoretical predictions of AO flux for that altitude to validate the design of the AO sensor. The preliminary analysis of the results of the flight test received to date has demonstrated that the silver-based AO sensor is working satisfactorily.

The results indicate that future work is required to construct several thinner silver films and other materials for comparison, characterize the temperature effect on erosion rate and reaction mechanism of AO in the oxidation layer and protect the silver film from oxidation and contamination before launch. Based on these results and improvements, a new AO sensor can be designed for CubeSat missions with the goal to obtain a more reliable and accurate AO flux.

Possibility of using video navigation for the determination of CubeSat separation parameters

E.V. Ustiugov

Samara State Aerospace University named after S.P. Korolyov, Samara, Russia

To provide navigation support for satellite separation from uncontrollable objects or unknown orientation object we need to know the separation parameters, for example, the CubeSat's separation from the upper stage. Data of separation parameters can be used as a first approximation for the CubeSat attitude determination and control subsystem (ADCS) without using the special sensors on board the CubeSat.

It is proposed to use video information to determine the separation parameters. The camera is mounted on the separation adapter and images the separation process. This method has several problems, such as the strict requirements for lighting, need to know the satellite geometry and the problems with the identification of the satellite's reference points (SRP). The lighting problem is solved by light illumination from the camera, based on LEDs. The geometry known problem is connected with the definition of distance to the satellite through the form factor and bind satellite's reference points to the geometric model. SRP identification is a problem only for a fully autonomous system.

The video images are processed and we obtain the satellite position and orientation at different times relative to the camera. The research on the observation of the separation parameters has shown that it is extremely difficult to solve the problem using only the images from the camera. To solve the navigation problem it is necessary to have more information about the orientation of the camera, or the satellite, or the direction and speed of the satellite separation. An algorithm for the case of a deployment from the Soyuz upper stage was developed. Based on the research with this algorithm, a system design approach was recommended using not only the images from the video navigation but also additional measurements of separation parameters.

This technology also provides reliable information concerning the deployment process which removes all questions from the customers. This approach can also be used to determine the rendezvous and docking conditions, which is useful for considering the space debris problem.

Theoretical Modeling of a Nanosatellite Separation Device Using a Magnetic Pulse Drive

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This poster provides a theoretical assessment of the forces produced by a pulsed magnetic field used to separate a nanosatellite from the upper stage of a launch vehicle after the primary payload has been released. In this scheme, a magnetic pulse drive is used to deploy the satellite instead of a standard deployer.

The motion of a nanosatellite in a magnetic pulsed field produced by an inductor is described by a system of integro-differential equations. The basic equation of motion of a nanosatellite deployed in the direction of its long axis by the electromagnetic pressure developed between the inductor and the nanosatellite is given in the poster, together with solutions to the equation system using the Runge-Kutta fourth-order method with initial conditions equal to zero.

The mathematical model allows analysis of the influence of various parameters of the magnetic pulse drive on the acceleration and force acting on the nanosatellite. The simulation results obtained for the separation velocity are in good agreement with the experiments.

The study was partially supported by RFBR, Research Project No. 13-08-97015-Volga Region_a.

The Choice of Parameters for CubeSat Separation from a Non-Oriented Upper Stage

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Piggy-back launches of CubeSats significantly reduce the expenses for the mission. Typically, each launch vehicle has a mass reserve which can be used for CubeSats. For CubeSat deployments it is possible to use the upper stages of launch vehicles which have low, near-circular orbits. For example, the upper stage of the Soyuz carrier rocket has an orbit with parameters 190 × 240 km (e = 0.0038), and the upper stage of a Proton-M carrier rocket has an orbit 170 × 230 km (e = 0,0046). The lifetimes of CubeSats in low-Earth orbit will not be very long, but for short-term experiments several days is enough.

Piggy-back launches require a deployer to separate the CubeSat from the upper stage. The choice of the deployment time and location, speed and direction has to be carefully selected. Since the CubeSat, the upper stage and the main payload, usually a primary satellite or satellites, have different ballistic coefficients, there is a danger of collision in orbit.

The probability of possible dangerous approaches between the Soyuz upper stage, the primary payload and a CubeSat was calculated. These calculations led to recommendations for dangerous approach prevention. The range of acceptable parameters of the CubeSat separation from an upper stage with random orientation was obtained. The separation velocity should be from 1 m/s up to the velocity of the main payload, and the time delay of the CubeSat separation after the primary payload separation should be from 5 s up to 20 s. The method of choice of separation parameters from a non-oriented platform can be used not only for piggy back launches from the Soyuz upper stage but also for other rockets.

The study was partially supported by RFBR, Research Project No. 13-08-97015-Volga Region_a.

Phased Antenna Array on the Ground for Nanosatellite Telecommunications

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One of the most promising directions in space technology is the development of pico- and nanosatellites. These satellites can significantly reduce the cost of scientific and technological experiments in comparison with traditional ‘big’ satellites. To perform a successful mission with a nanosatellite, which is usually placed in a low-Earth orbit (LEO), it is extremely important to provide a reliable communications channel.

To provide this kind of communication special ground segments are traditionally used. For instance, university satellites can use the Global Educational Network for Satellite Operations (GENSO) to provide a telemetry channel, but it is not that simple to have a more wideband connection, which also requires higher frequencies. One of the most problematic issues is the ground station antenna. Parabolic, mechanically steerable antennas are the most commonly used, but they are quite expensive in production and use.

Analysis of existing technical solutions shows that a phased antenna array can also be offered for the satellite communication. Such phased antenna array could be a relatively inexpensive solution for the reception of S-band radio signals from low-orbit satellites (~630 km altitude).

In case of LEO satellites we have some specific requirements for the antennas. One of them is the directivity gain. According to preliminary calculations its acceptable value is about 28 dB. For the simulation, a phased antenna array consisting of 196 simple rectangular microstrip radiation elements was chosen. To perform electrodynamic simulation, the specialized software FEKO has been used (FEKO stands for FEldberechnung für Körper mit beliebiger Oberfläche which means “field calculations for bodies with arbitrary surfaces”). Solution of the simulation task of radiation element was achieved using the Method of Moments (MoM). For the detailed simulation of phased antenna array operation in Matlab phase shifters providing shift value up to 110º were used. Simulation has shown that the directivity pattern with the gain of 29.15 dBi could be achieved.

Preliminary calculations and the simulation mentioned above showed that it is possible to develop an antenna array consisting of 196 microstrip radiators and phase shifters, with the resulting directivity gain about 29 dBi, a main lobe width of 10º and a steering angle of ±20º. The simulation was performed on the assumption that the signal’s band is about 240-250 MHz.

It is now planned to create a physical prototype of the phased antenna array for the reception of radio signals from LEO satellites.

Joint Use of Different Types of Information in the Samsat-1 Nanosatellite Determination Algorithms

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It is supposed to check the algorithm of orientation determination using the minimum measuring means combination on the SamSat-1 nanosatellite. To solve this problem information from the following sources is used: navigation receiver, magnetometer and solar panels.

The mathematical definition of the nanosatellite orientation determination based on the different types of information complexing can be presented in the following way. On the basis of the measurements receiving from the sources: 1) magnetometer: the measured Earth magnetic vector in the body frame; 2) navigation receiver: navigation decisions (the trajectory parameters of the center of mass), the numbers of visible/invisible navigation satellites of the satellite radio navigation systems GLONASS/GPS, ephemerides of the navigation satellites of the GLONASS/GPS; 3) solar panels: telemetric information about the current from the solar panels; - it is necessary to find the spatial nanosatellite orientation (to estimate the transfer matrix from the body to the base frame).

While solving this problem the following algorithms are used:

- Algorithm based on the tightly coupled integrating scheme that is understood as the scheme in that the orientation determination problem is solved with the use of all measured information simultaneously.
- Algorithm based on the loosely coupled integrating scheme that is understood as the scheme in that the orientation determination problem is solved step by step using information as needed.
- Algorithms based on the analysis of navigation satellite visibility/invisibility. The spatial nanosatellite axes orientation determination (two orientation angles determination in the presence of one navigation antenna) and spatial nanosatellite orientation determination (three orientation angles determination in the presence of three navigation antennas) according to the analysis of spatial location of visible/invisible navigation satellite.

As a result of the problem solution the adaptive algorithm was developed. It takes into account the presence/absence of different information types and allows determining the one-moment nanosatellite orientation with the accuracy of about 10º.

This study was partially supported by RFBR, Research Project No. 12-08-31516 mol_a.

Preliminary Results for the NTNU Test Satellite CubeSat Bus

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NTNU is currently engaged in the CubeSat project NUTS (NTNU Test Satellite). The electronics of most CubeSats are still being built around a ten-year old de-facto standard of the PC-104 form factor. The NUTS project proposes a different approach, offering strengthened data bus and power supply lines and an easier access to the different electronic subsystems. This will make handling and working with the satellite during the development, integration and test phases easier. The concept is using a backplane layout where cards for other systems can be slotted in. Through the backplane all subsystems will get access to power and a communication bus, and two subsystems will be able to act as controllers/supervisors for the rest.

The NUTS CubeSat platform will make use of the CubeSat Space Protocol (CSP) for communication between the different modules, as well as for the downlink. This protocol takes care of the necessary routing and packet forwarding between nodes in the network. CSP supports different physical layers, e.g. USART and I2C, and it can be used over the radio link between the satellite and the ground station. The low power internal wireless system used in the bus will enable modules to communicate on higher bit rates than provided by the I2C interface. The wireless bus will also use CSP.

The first satellite using this bus is the NUTS satellite, planned to be launched late 2014. This satellite will also be demonstrating the use of composite materials as the main satellite structure. An engineering model of the satellite is currently being developed. This paper will discuss the design of the NUTS CubeSat bus, preliminary test results and experiences from the lab tests.

Assessment of the Use of Deployable Solar Panels on SNUSAT-1

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In cooperation with the QB50 Project, Seoul National University is developing a 2U CubeSat, called SNUSAT-1. Currently, the QB50 mission is planned to be launched in Brazil, using a Ukrainian launcher, Tsyklon-4. The orbit will be a circular, Sun-synchronous orbit at 380-400 km altitude, with a lifetime of 7-9 months, depending on the level of solar activity at the time of the mission. SNUSAT-1 must be designed to be capable of performing a QB50 science mission, Fault Detection, Isolation, & Recovery (FDIR) mission, camera demonstration and a CubeSat drag coefficient modelling mission.

SNUSAT-1 must continuously perform attitude control, acquire lower thermosphere data as well as locate its position, and download acquired data of at least 2 Mb per day. Combining the power required for nominal operation, power generation from the side panels of SNUSAT-1 might not meet the requirements under all orbit conditions.

This research focuses on the assessment of using deployable solar panels on SNUSAT-1 within the total mass and volume constraints of the system. The performance of the solar panels is analysed for various operational cases. Furthermore, an optimal battery capacity for SNUSAT-1 is proposed for the case of using a deployable solar panel.

Design of a Maneuvering Unit for 3U CubeSats

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The paper discusses basic design aspects and orbit control capabilities of a 3U CubeSat, carrying a Maneuvering Unit (MU). The MU could be used for

- transferring the CubeSat to a higher orbit to extend its lifetime if the initial orbit is very low, or for
- transferring the CubeSat to a lower orbit, if the initial orbit is too high, in order to be compliant with the maximum orbital lifetime of 25 years, as stipulated in the Code of Conduct.

The MU is a cube with dimensions of 10×10×10 cm and a mass of less than 1.2 kg, compliant with the CubeSat standard. It is assumed that this unit is part of a 3U CubeSat, which includes also the unit of support systems (1U) and the payload unit (1U).

At the beginning of the design process, existing types of propulsion systems were reviewed. It was concluded that the requirements were best met by a propulsion system based on solid fuels. Advantages of these thrusters include simplicity of design, high reliability, ease of operation, low cost of manufacturing and testing.

It was calculated that solid fuel thrusters could increase the orbit of a 3U CubeSat from 190×240 km (in the case of starting with the orbital stage of the launch vehicle Soyuz) to 372×386 km, which will increase the lifetime of the CubeSat from 7 to 98 days.

A Maneuvering Unit can also be used to lower the orbit of a nanosatellite if the initial orbit, as required by the primary satellite payload (usually a large satellite), is rather high. For example, the lifetime of a nanosatellite in a circular orbit at an altitude of 1000 km is considerably more than 25 years which is in conflict with the International Code of Conduct. The MU allows to lower the orbit to 631×1000 km at the end of the mission. In this orbit the lifetime of a nanosatellite would be less than 5 years.

Including a Maneuvering Unit in a 3U CubeSat will significantly extend the range of the possible use of nanosatellites and create cheaper access to space for universities and small innovative companies.

Development of Kazakhstan's First Nanosatellite

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The development of national satellites is supported by the space program of the Republic of Kazakhstan. Development of small satellites is part of this program. It is planned to develop an experimental prototype of a 3U CubeSat, where the main operation modes of an AOCS and its software are developed by specialists in Kazakhstan. A scientific experiment for studying the Earth's magnetic field will also be accommodated on the CubeSat.

At present, preliminary calculations of the mass and power budgets, the volume requirements, structural analysis, simulation modeling for determination of parameters of the AOCS and analysis of the communication system are being carried out.

Status of the High-Reliability Electrical Power Supply of the OUFTI-1 CubeSat

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We report on the current status (Feb 2013) of the design, architecture, implementation, and tests of the electrical power supply (EPS) of the educational 1U OUFTI-1 CubeSat. The work on the EPS subsystem started in the summer of 2008. Not surprisingly, the required functionalities and capabilities of the EPS changed many times over the last four years. The main reason for this are the many changes in the operating voltages and currents required by the other subsystems, especially by the VHF/UHF telecommunications (COM) subsystem, consisting of a DSTAR/AX.25 voice and data transceiver and in an OOK emergency beacon. In particular, circumstances and trade-offs led us to change, on several occasions, the frequency assignment for the uplink (now 435 MHz) and downlink (now 145 MHz), with direct consequences on the link budgets, the selection of the appropriate RF power amplifier circuits, and the required voltages and currents. Due to the many iterations of the design over the years, several new people have had a chance to examine the EPS with fresh eyes and suggest ideas to make it increasingly more reliable. We have progressively converged towards a design that is highly modular and flexible and can cope with various faults, while remaining as simple as possible.

The main EPS functionalities are

- collecting energy from the solar cells and storing it in batteries,
- dissipating excessive power,
- protecting the batteries in voltage and temperature,
- providing currents to the thermal cutters used for antenna deployment,
- providing the required currents at appropriate voltages to the client subsystems,
- protecting the switching converters and clients (mainly COM subsystem, two on-board computers (OBCs), one commercial off-the shelf and the other built in-house, and analog-to-digital converters for measurements of physical parameters, such as voltages, currents and temperatures),
- acquiring several such measurements,
- allow monitoring and recharging of the batteries on the ground,
- handling the remove-before-flight and deployment switches.

The heart of the EPS consists in three buck-boost switching converters. Two are connected in parallel through diodes to provide, at 3.3 V, the appropriate currents for the COM subsystem (except for the beacon) and the OBC built in-house; one provides, at 5 V, the appropriate current for the off-the-shelf OBC and the beacon. For the supply at 3.3 V, we verified experimentally that the two converters would each contribute almost half of the total output current, and that either would automatically step up to the total current in case of failure of the other. Each converter is surrounded by appropriate filters and protections (both electronic and fuse-based).

For the latest version of the EPS, we built a six-layer printed circuit board in the standard CubeSat format, and we have successfully tested it in the laboratory.

Innovative Technologies for CubeSats by NLR

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The National Aerospace Laboratory (NLR) is the central institute for aerospace research in the Netherlands. Its principal mission is to render scientific support and technical assistance on a non-profit basis to Dutch and foreign aerospace industries and organisations, civil and military aircraft operators and governmental agencies concerned with aviation and space flight.

NLR's Space Systems Department has been involved in technology development for CubeSats since the beginning. A poster will present an overview of recent technology developments such as:

- A Payload Data processing Module (PDM), an advanced processing and storage device for CubeSats. The PDM is compact, lightweight, low power and is developed for both Triton AIS 3U CubeSats of ISIS B.V., expected to be launched in 2013.
- An Electrical Ground Support Equipment (EGSE) for Attitude and Orbit Control Systems (AOCS) of CubeSats. This test bench provides a basis to support the attitude and orbit control systems for the two 3U DelFFI CubeSats of TU Delft, flying in formation as part of QB50.
- Thermal control technology to provide low-cost thermal solutions for increasing complexity, size and power consumption needs of CubeSats.

Simulation of Energy Produced by Solar Panels to Validate the Balance of Electrical Power in CubeSats

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CubeSats are small satellites with a cube-shaped structure that carry solar panels on their outside faces to generate the power needed in orbit for the operation of the subsystems of the CubeSat. It is therefore necessary for the electrical and electronic components of the CubeSat to be tested before operation in orbit to meet the level of reliability that is required for the application in question.

This paper proposes a model to simulate the power produced by solar panels for testing the charge and discharge of batteries in the power supply subsystem of the CubeSat. The validation of the simulation shown in this work is performed through tests on a prototype developed for this purpose. The positive results observed in the tests suggest that the simulation is able to represent the main conditions for the production of energy by the solar panels when the CubeSat is in orbit.

Comparison of the effectiveness of different kinds of radiation shields on a CubeSat

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Space is a harsh environment in which electronic equipment must be shielded effectively against radiation. The sources of radiation are solar energetic particles and cosmic rays. Earth is protected from these particles by its atmosphere and by its magnetic field which traps the energetic charged particles in the Van Allen belts.

Without taking precautions serious damage can arise when energetic particles penetrate a satellite's structure: memory bit alteration, destructive latch-up, long-term alteration of semi-conductor crystalline structure, etc.

This poster describes an experiment intended for a CubeSat which will compare effects of radiation on analog and digital components protected by different kinds of shields. The experiment is accommodated on a 10x10 cm board and consists of a supervisory circuit, a radiation sensor and three similar zones called test zones. The zones contain analog (operational amplifier) and digital (microcontroller) COTS circuits. In the first zone the circuits are not protected by a shield. It is the reference zone. The two other zones are protected by different kinds of shields. The supervisory circuit will measure radiation and will compare the behavior of the three test zones during the flight. All the data will be forwarded to the on-board computer and then transmitted to Earth via a radio link. An engineering model of the board has already been designed and tested.

Architectures of Ground and Space Segments of OUFTI-1

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We present a bird's eye view of the complete OUFTI-1 satellite system, i.e. its ground and space segments, and their interconnection. The main payload on the 1U OUFTI-1 is, in essence, a D-STAR repeater in space (potentially the first one ever); D-STAR is an amateur-radio ("ham"), digital radio-communication protocol (with associated equipment) allowing the simultaneous transmission of voice and data (such as GPS coordinates and call-signs).

Our electronics consists of five boards

- electrical power supply (EPS),
- telecommunications (COM),
- main on-board computer (OBC) built in-house,
- backup, commercial, off-the-shelf OBC with flight history (from Pumpkin),
- emergency beacon (BCN).

The COM subsystem, which enables the link between space and ground, provides three capabilities: D-STAR voice and data communications, AX.25 telecommand and telemetry (TC/TM), and OOK emergency beacon transmissions.

The satellite simultaneously receives and decodes potential D-STAR and AX.25 communications, but transmits in only one of these modes at a time. To make the beacon highly reliable, we implemented it as two parallel, independent (except for a transfer of parameters to be transmitted) chains up to, but excluding, the radiofrequency (RF) power amplification, and we decoupled it as much as possible from the rest of the electronics. The chains operate in alternation, each sending 12 vital parameters to the ground, four of which are common.

The ground segment consists of a ground station, a standard D-STAR repeater (for ground communications), and a satellite extension to the latter. The ground station consists of fixed RF installations in Liège and Redu and one or more control computers (implementing the "Mission Control Center"), which can be laptops, tablet-computers, or smartphones, making it possible to control the satellite from anywhere in the world via Internet. The control station is fully automated and has been operational for two years. It is used routinely for tracking amateur-radio satellites. It will be used to send telecommands and to receive telemetry, both in AX.25. The detailed format and usage of the TC/TM has been defined. It is compatible with the ESA CCSDS standards. Furthermore, the ground station meets the GENSO standards, meaning that it can be integrated into the worldwide GENSO network. The D-STAR satellite extension has been designed and some elements developed and tested, but it still needs to be implemented. The role of the extension is essentially to add OUFTI-1 to the worldwide network of D-STAR repeaters, which are connected via the Internet and microwave links.

We will present system block diagrams of the satellite, the control station, and the D-STAR repeater and its satellite extension, and discuss the reasons that led to the current architecture of the overall OUFTI-1 system. The system is expected to be fully operational by mid 2013.

PW-Sat2, the Second Polish Student Satellite

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The PW-Sat2 2U CubeSat is the follow-on project to the PW-Sat 1U CubeSat, launched on 13 February 2012 on the Vega Maiden Flight. PW-Sat2 is aimed at testing two innovative technologies, a newly developed system for de-orbiting and a new Sun sensor. It will also carry two cameras.

A system for de-orbiting was already developed for PW-Sat. On PW-Sat, the system employed a tail-like structure. The PW-Sat2 system for de-orbiting is different from the previous version. The PW-Sat2 system will be a sail deployment structure made of shape-memory material and Mylar foil.

The Sun sensor was a bachelor thesis of one of the students who took part in the project. The sensor is simple, has low-power consumption and high accuracy and is, therefore, ideal for small satellites and university CubeSat missions. The sensor provides precise calculations of the coefficient describing the strength of the signal as a function of the whole range of angles of the sunlight incidence on the sensor. The Sun sensor accuracy, depending on its level of advancement, has also been taken into account. The main advantages of this concept are the high level of accuracy and reliability as well as the simple construction and use of relatively cheap, readily available materials.

The additional payloads are two cameras, one pointed at the Earth, the other to record the sail deployment. SSTV (Slow-Scan Television) transmission from the cameras will be also available.

The project duration is approximately 2.5 years. The official beginning of the project was 4 January 2013. The educational goal is to educate more than 30 space engineers. About 10 students are expected to obtain their diplomas and make an internship on PW-Sat2 payloads and subsystems. We believe that participation in this project will help students to find workplaces in the Polish space sector.

SwampSat, a Demonstration of Miniaturized Control Moment Gyroscopes for Rapid Retargeting and Precision Pointing of Pico- and Nanosatellites

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Compared to traditional monolithic satellites, nano- and picosatellites have more stringent constraints on their size, weight, and power (SWaP). One key technology that will enable new mission opportunities for nano- and picosatellites is a precision three-axis attitude control system.

SwampSat, a 1U picosatellite, designed and developed by the Space Systems Group at the University of Florida, is designed for on-orbit demonstration of a compact three-axis attitude control system capable of rapid retargeting and precision pointing. SwampSat utilizes four miniaturized single gimbal control moment gyroscopes (CMGs) in a pyramidal configuration as actuators. A successful SwampSat mission will raise the technology readiness level of these control moment gyroscopes.

SwampSat is manifested on NASA's Fourth Educational Launch of Nanosatellites (ElaNa) mission and is scheduled to launch in the summer of 2013. This paper discusses the research and development that has culminated in the technology to demonstrate rapid retargeting and precision pointing on a 1U platform, while satisfying the SWaP constraints. The paper also highlights some of the pros/cons of CMG usage for pico- and nanosatellites.

International Benefits Provided by the Open Prototype for Educational NanoSats

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The University of North Dakota is currently housing a student-led small satellite development initiative by the name of OpenOrbiter. The project is an interdisciplinary, interdepartmental effort that has involved over 200 students from disciplines including engineering, space studies, computer science and business.

The OpenOrbiter spacecraft is being built to comply with the CubeSat standard and is planned to be launched through NASA's Educational Launch of Nanosatellites (ElaNa) program. The spacecraft is being entirely designed and developed by students who also make all decisions.

One of the most important elements of the OpenOrbiter project is the development of the Open Prototype for Educational NanoSats (OPEN) documentation. OPEN is a set of design specifications for CubeSats that will drastically lower the component cost of CubeSats. Where a typical CubeSat will cost anywhere between $40,000 and $200,000 to develop, an OPEN-based CubeSat can be built for less than $5,000 in parts cost, payload excluded. The OPEN specifications will include hardware blueprints, software code, schematics and instructions for construction and an operations plan. It will be made available to the public free of charge under the Creative Commons with Attribution license. It essentially is a set of instructions for CubeSat development with a standardized payload bay that in theory could become plug and play.

OPEN will help bridge the gap between resource-rich and resource-constrained institutions. By drastically reducing the development cost of the satellite, it is believed that more universities, colleges and even high schools can become involved in spacecraft development. Further, by exciting students and young professionals about spacecraft development, OPEN can serve as an additional pathway into science, technology, engineering and math (STEM) education.

The reduced development costs are realized both in terms of hardware and software costs, as well as in labor hours, where most testing and space-qualification will already have occurred.

The OpenOrbiter project is currently under development and significant progress has been made. Most of the components that will be used in the satellite have already been identified. The hardware is currently undergoing rigorous testing and space-qualifying procedures and the software is being written and tested. A low-level functioning prototype unit is also under construction. The OpenOrbiter spacecraft is planned for launch in 2014, with the official release of OPEN documentation to occur in the months to follow.

TwinCube – a Tethered Satellite System accommodated in a 3U CubeSat

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TwinCube is a proposed nanosatellite designed to perform scientific and technological experiments on a tethered satellite system. The structure of the nanosatellite will be a standard 3U CubeSat that will be divided in orbit into two subsatellites connected by a 1 km long tether. Each subsatellite will be equipped with all the essential subsystems necessary to maintain its independence.

The main goal of the mission is to perform two-point diagnostic measurements of electromagnetic emissions in near-Earth plasma. Multi-point measurements play a significant role in understanding energy flows driven by the Sun as well as terrestrial activity. Therefore, each subsatellite will carry a Radio Frequency Analyzer capable of performing passive diagnostic measurements of the electromagnetic field. Since CubeSats are expected to be low-cost and robust, development of a small and efficient plasma diagnostic tool for a hardware-restrained CubeSat platform, in contrast to full-scale scientific instrumentation that already has flight heritage, might be important also for future space cluster missions. Moreover, to achieve significant miniaturization, an ultra-light antenna is planned to be used. First technology demonstrators show that it is possible to design a 1 m long boom antenna with release mechanism with a mass of only 34 g.

Tether operations are another important aspect of the mission. Even though the tether is developed primarily to support the two-point plasma measurements, the engineering and scientific problems, such as tether winding and unwinding, system dynamics and its controllability are of importance in their own right Therefore, the second goal of the tether experiment is to simulate and verify the dynamics of the system and to learn how to control its behaviour, in particular oscillations (induced by gravity gradient) and its spin. Preliminary simulations that were already conducted show that it may be possible to achieve control of the system by lengthening/shortening of the tether and by using angular energy dissipation mechanism.

The TwinCube mission was proposed in response for ESA's Educational Office CubeSat initiative. The technological and scientific challenges encountered during the realization of the project will allow a number of master and PhD students to extend their knowledge in the field of "Space Project" realization.

Open Source Educational CubeSat

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We have developed an open source low-cost educational CubeSat with the aim of bringing CubeSats into even more classrooms and universities. The first four open source educational CubeSats were very successfully used during the Ventspils CubeSat Workshop in February 2013. This new educational satellite combines high technology with low-cost open source. It has everything on board to allow understanding the design of real satellites, like a Li-Ion battery with charge protection, a reaction wheel and magnetic torquers, as well as a 2.4 GHz transceiver and a GPS receiver. The educational CubeSats are easily programmable through the Arduino development environment which allows for fast and easy software uploads, e.g. for testing ACS algorithms.

Students can see the interiour through four acrylic sides of the educational CubeSat while the other two sides are covered with solar cells. The educational CubeSat has additional temperature, current and voltage sensors. All schematics, software and layout files are delivered with the CubeSat which makes it an ideal tool for teaching physics, electronics, and applied satellite technologies at schools and universities.