UNIVERSITY SATELLITE MISSIONS AND CUBESAT WORKSHOP 2020

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ORGANIZERS

The International Academy of Astronautics (IAA)

IAA was founded in 1960 by Theodore von Kármán. The Academy is an independent international community of leading experts committed to expanding the frontiers of space, the newest realm of human activity. To foster the development of astronautics, the Academy undertakes a number of activities, including the recognition of outstanding contributors through elections and awards. It also facilitates professional communication, develops and promotes new ideas and initiatives, engages the public, and fosters a sense of community among the members. The IAA is a unique non-governmental organization established in 1960 and recognized by the United Nations in 1996.

It is an honorary society with an action agenda. With 1200 elected members and corresponding members from 87 nations, it works closely with space agencies, industry, the academic community and the national science and engineering academies to determine needs and objectives and to help the shape policy and forge cooperation by means of studies, position papers, conference and publications. The IAA has published nearly 60 studies to date and it engaged in the preparation of 40 others. The Academy also publishes the journal *Acta Astronautica* containing refereed papers. The Academy now organizes 20 conferences per year and regional meetings focused on development and promotion of new initiatives. This activity also includes, in cooperation with the International Astronautical Federation and the International Institute of Space Law, the traditional contribution to the International Astronautical Congress (IAC), where the Academy sponsors 13 Symposia. The Academy also continues to enjoy its participation in the COSPAR Assemblies by sponsoring and co-sponsoring symposia and the International Society for Photogrammetry and Remote Sensing (ISPRS) congress this year in Prague. Although the IAA has many connections to these and other similar organizations, it is distinctive as the only international Academy of elected members in the broad area of astronautics and space.

Group of Astrodynamics for the Use of Space Systems (GAUSS)

GAUSS is an Italian limited liability company based in Rome, founded in 2012 as a spin-off of the *Scuola di Ingegneria Aerospaziale (Aerospace Engineering School)* of *Sapienza* University of Rome, carrying on the school's more than twenty years tradition in the field of microsatellites.

Its founders include Prof. Filippo Graziani, former dean of the Aerospace engineering faculty.

Active in the space technology field, its aims are the research, the development and the implementation of aerospace projects, plus the educational aspect and the execution of related cultural initiatives.

GAUSS Srl has gained its experience from differently shaped and sized satellites' launches. The company business is mainly related to the design and the manufacturing of micro, nano, pico and femto satellites, intended as CubeSat, PocketQube and releasing platforms such as GPOD, MRFOD and TUPOD.

In the most recent launches, UniSat was also a platform and it was able to release CubeSats, thus letting GAUSS being a small satellites launch provider.

GAUSS activities include also structural design, realization and integration of the main subsystems and payloads and all the ground segment operations. The scientific and educational mission of the company is also important: several experiments are boarded on the microsatellites, ranging from space debris observation instruments to space bio-medicine.

Since 2009, GAUSS has been performing bio-medical research in space and on 2011 it was able to conduct two bio-medical experiments on board the Space Shuttle. Since then, space biomedicine payloads research has been carried on.

Since 2000, GAUSS Srl has launched satellites with the support of "International Space Company" (ISC) Kosmotras, using the Dnepr LV.

The UniSat Program started in the early nineties thanks to Professor Graziani whose main purpose was to give an "hands-on" education to the students of the School of Aerospace Engineering ("Sapienza" University of Rome).

The first microsatellite, UNISAT, was completely manufactured by the University students and launched in September 2000. It was followed by UNISAT-2 (December 2002), UNISAT-3 (June 2004), UNISAT-4 (July 2006), EduSat (August 2011), UniCubesat-GG (February 2012).

On 2012, GAUSS became a limited liability company where young people and former students of the School continued to design and manufacture microsatellites.

GAUSS' major achievements are:

- UNISAT-5, launched in November 2013 from the Yasny Cosmodrome (Russia);
- UNISAT-6, launched in June 2014 from the Yasny Cosmodrome (Russia).
- The on-going project is UNISAT-7 which is planned to be launched in 2021.

FOREWORD

Having reached the fifth edition of the conference I would like to retrace with you the path taken so far together.

Ten years ago, when we organized in Rome the 1st IAA Conference on University Missions & Cubesat Workshop, Cubesat had just been invented by Professor Bob Twiggs and Jordi Puig-Suari. The motto we chose was the Latin sentence: “Quo Vadis, Cubesat?” (“Where are you going, Cubesat?”) because nobody could imagine how far they would go.

Since the beginning, Cubesats have attracted university students and teachers due to their accessibility – low cost and relative simplicity – and have become an exciting way to gain experience.

In 2013, they were still considered “student’s toys”: that’s the reason why the 2013 Conference cover was represented by two Roman Gladiators playing dice with Cubesats!

Nobody could believe their development and that their applications could give new perspectives in scientific and industrial missions such as biomedical space research, life science, space exploration, and space debris observation.

However, the results obtained by universities have opened doors to the commercial use of Cubesats.

The motto of the Third Conference was “Navigating into Space” since in 2015 the Cubesats were already directed towards other planets.

The Flyer of the Fourth Conference in 2017 wants to confirm that one of the main purposes of universities is to spread culture around the world; as via Appia did in Ancient Roman times, bringing people outside the city.

The present meeting “Getting Closer to Mars” reveals the interest of the Cubesat for solar system exploration missions.

Today, Cubesats are no longer considered mainly as an educational instrument for “university science” or “student’s toys” but are becoming more industry-oriented and bring together the big world, encouraging international cooperation.

This is also shown by this conference where more than 130 participants from about thirty different countries are giving their contribution.

I hope that this conference leaded to fruitful collaborations and presented an excellent opportunity to share research, recent findings, future projects and new ideas with all the community dedicated to space activities.

This long journey would not have been possible without some people to whom I care and to whom I extend my warmest thanks.

First of all, thank you to Dr. Jean-Michel Contant, and his wife Thérèse, for his dedication and perseverance with the work as General Secretary of the Academy and for his constant support to our Conference series.

I thank European Space Agency for making available Student Sponsorship, and the Italian Space Agency represented this year by Dr. Enrico Cavallini.

DHV Technology, GMV Innovating Solution, BCC Roma and The American Astronautical Society and Univelt Incorporated, supported us like every year, and I want to renew them my thanks.

I also want to mention the exhibitors of the 5a edition of the Conference which are, ISISpace, Astroberry, China Academy of Launch Vehicle Technology and again DHV Technology.

Moreover, I would like to thank all members of the Scientific Committee that with their competences and experience helped to evaluate best papers and remarkable works. Many thanks to the chairmen and all the lecturers for sharing with us their presentations. Thanks to Prof. Paolo Teofilatto, Dean of the School of Aerospace Engineering of Sapienza University of Rome.

Least but not last, a very special thanks goes Dr. Vladimir Andreev and his wife Inna. I have known Dr. Andreev, Founder of ISC Kosmostras and Dnepr Programme since 20 years ago, and after having collaborated such a long time I consider him as a dear friend.

Thank you to Dr Alexander and Maxim Degtyarev, to our best consultant Vladislav Solovey and to all GAUSS staff, including the media reporter Olga Ovchinnikova, to have helped to make this event a success!

Rome, 1st February 2020

Filippo Graziani
IAA Member,
Senior Professor,
GAUSS Srl President

Group picture at the Conference venue

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CONSTELLATIONS AND FORMATION FLYING

Session Chair:
Giovanni B. Palmerini

IAA-AAS-CU-20-01-01
AAS 20-201

ATTITUDE CONTROL ALGORITHMS IN A SWARM OF CUBESATS: KRIGING INTERPOLATION AND COORDINATED DATA EXCHANGE

Anton Afanasev,[*] Anton Ivanov,[†] Ahmed Mahfouz, and Dmitry Pritykin[‡]

This study is a part of the Skoltech University project to deploy a swarm of four identical 3U CubeSats in LEO. The CubeSats are to be equipped with gamma-ray sensors and their collective behavior will be exhibited in detecting gamma-ray bursts and coordinated attitude control. We consider a fully magnetic attitude control system, comprising a magnetometer as a part of attitude determination routine and three orthogonal magnetorquers as actuators. Having implemented and tested the conventional three-axis magnetic attitude determination and control algorithms, we proceed to study how the performance of such ADCS may be enhanced by using measurements and state vectors exchange. We interpolate the exchanged data, using the Kriging algorithm in conjunction with Extended Kalman filter and Lyapunov-based controller, since it provides the auto-correlation and variance information about the environment of the magnetic field, which is of utmost importance for heterogeneous and noisy fields. In our simulations we compare the performance of the controller for a single satellite to that of the satellite in the swarm of CubeSats, which maintains the form of a regular tetrahedron and carries out distributed measurements with interpolation. Improved attitude stabilization for the latter scenario is demonstrated by mean squared errors. [View Full Paper]

[*] PhD Student, Space Center, Skolkovo Institute of Science and Technology, Bolshoy Boulevard 30, bld. 1, Moscow, Russia 121205.

[†] Director, Space Center, Skolkovo Institute of Science and Technology, Bolshoy Boulevard 30, bld. 1, Moscow, Russia 121205.

[‡] Senior Researcher, Space Center, Skolkovo Institute of Science and Technology, Bolshoy Boulevard 30, bld. 1, Moscow, Russia 121205.

IAA-AAS-CU-20-01-02
AAS 20-202

COLLISION AVOIDANCE FOR SATELLITES IN FORMATION FLYING

Karthick Dharmarajan,* Giovanni B. Palmerini,† and Marco Sabatini‡

According to later reports there are more than 18000 artificial satellites in space, with more than 35000 objects larger than 10cm and another million objects large enough to cause serious damage to the satellites. With so many potentially dangerous objects in an orbit around the surface of the earth, a collision-avoidance system becomes often necessary. This problem is of greater concern with the ever-increasing number of satellites that are being planned with multiple new projects involving large constellations. There is an increasing need for the design and implementation of specific operations to avoid collisions in space. These collision avoidance manoeuvres depend on having a good knowledge of orbit parameters of both the controlled and the colliding satellites. Another factor to be considered is the impulse required and the available propellant to perform the collision avoidance manoeuvres. Optimization of propellant usage is a necessary step while performing these manoeuvres because the allocated resources for a potential collision avoidance manoeuvre are very low. We consider here a deterministic approach, neglecting uncertainties in the knowledge of the kinematic state of the colliders. The proposed optimization technique solves an eigenvalue problem for a case of non-direct approach. The effect of the manoeuvre's anticipation time with respect to the foreseen possible collision is highlighted, and specific detail is given to the in-plane and out-of-plane components of the impulsive manoeuvre indicated in order to avoid such an event. The cases investigated are relevant to formation flying in LEO. In addition, some preliminary analysis about the feasibility of the manoeuvres by means of propulsion subsystems currently available for microsatellites is reported. [View Full Paper]

* PhD Candidate, Dipartimento di Ingegneria Astronautica, Elettrica ed Energetica, Sapienza Università di Roma, Italy.
† Professor, Scuola di Ingegneria Aerospaziale, Sapienza Università di Roma, Italy.
‡ Researcher, Dipartimento di Ingegneria Astronautica, Elettrica ed Energetica, Sapienza Università di Roma, Italy.

IAA-AAS-CU-20-01-03
AAS 20-203

ITERATIVE LEARNING CONTROL PROCESSES ON-BOARD CUBESATS

Federica Angeletti[*] and Paolo Iannelli[†]

Tiny platforms as CubeSats are proving capable to ever more challenging missions. Increased performance certainly builds on the continuous technological advances in miniaturization, i.e., strictly speaking, in more tight hardware integration. However, part of the capabilities are – and surely will be more and more in a close future – due to improvements in the intelligence onboard, to better exploit the hardware possibilities. AI techniques ranges from evolved adaptive control to more autonomous, smarter processes, and their application should follow an incremental path. Along this path, Iterative Learning Control (ILC) can be considered as a small, yet already available step, applicable when a sequence of repetitive actions is foreseen. Main idea below is the analysis of the past experience, intended as the recorded behaviour during the mission, to more effectively act in future occurrences. By purposely designing the controller the computational burden required to provide a noticeable performance improvement can be quite limited, making ILC an interesting option. In the specific case of CubeSat missions, ILC application can be considered for attitude manoeuvre (especially the slewing required in Earth Observation mission) as well as during manoeuvring phase to correctly manage the frequent, off-nominal behaviour of the minute subsystem allowed onboard these platforms. After a quick and effective rehearsal of the ILC technique principles and status, this proposed paper aims to discuss possible applications of the iterative learning control technique to CubeSat missions, and to evaluate, through ad hoc numerical simulations, the advantages attainable by its adoption. [View Full Paper]

[*] Mechanical and Aerospace Engineering Department, Sapienza University of Rome, Italy.
E-mail: federica.angeletti@uniroma1.it.
[†] Mechanical and Aerospace Engineering Department, Sapienza University of Rome, Italy.
E-mail: paolo.iannelli@uniroma1.it.

IAA-AAS-CU-20-01-04
AAS 20-204

THE HERMES MISSION: A CUBESAT CONSTELLATION FOR MULTI-MESSENGER ASTROPHYSICS

Francesca Scala,[*] Giovanni Zanotti,[†] Serena Curzel,[‡] Mirela Fetescu,[§] Paolo Lunghi,[**] Michèle Lavagna,[††] and Roberto Bertacin[‡‡]

The High Energy Rapid Modular Ensemble of Satellites (HERMES) is a project that plays a key role in the Multi-Messenger Astrophysics of the next decade. The implementation of a distributed space asset to continuously monitor the random electromagnetic emissions of bright high-energy transients in the Universe is proposed. Specifically, the technological and scientific pathfinder constellation, up to six 3U CubeSat, embarks a new generation of miniaturised detectors for science. Having just closed the PDR, the project goes into phase C&D: Politecnico di Milano, together with INAF, oversees the space segments and payload implementation, respectively. The challenging mission feasibility was assessed from both technological and scientific points of view. The possibility to correctly keep the spacecraft triplets geometry and to ensure the correct overlapping of instrument field-of-view for a successful triangulation of high-energy transient has been achieved with no orbital control on board. The paper, starting from an introduction on scientific mission constraints, focuses on the description of platform subsystems design. The constellation complexity is highlighted in terms of pointing accuracy, power demand, and scientific data packages transmission. The program is co-funded by the National Ministry for Research (MIUR), the Italian Space Agency, (HERMES-TP), and the EC-H2020 framework (HERMES-SP). [View Full Paper]

[*] PhD Candidate, Politecnico di Milano, Department of Aerospace Science and Technology, Via La Masa, 34, 20156, Milano - Italy. E-mail: francesca1.scala@polimi.it.
[†] PhD Candidate, Politecnico di Milano, Department of Aerospace Science and Technology, Via La Masa, 34, 20156, Milano - Italy. E-mail: giovanni.zanotti@polimi.it.
[‡] PhD Candidate, Politecnico di Milano, Dipartimento di Elettronica, Informazione e Bioingegneria, Via Ponzio 34/5, 20133, Milano - Italy. E-mail: serena.curzel@polimi.it.
[§] MSc Student, Politecnico di Milano, Dipartimento di Elettronica, Informazione e Bioingegneria, Via Ponzio 34/5, 20133, Milano - Italy. E-mail: mirela.fetescu@mail.polimi.it.
[**] Assistant Professor, Politecnico di Milano, Department of Aerospace Science and Technology, Via La Masa, 34, 20156, Milano - Italy. E-mail: paolo.lunghi@polimi.it.
[††] Full Professor, Politecnico di Milano, Department of Aerospace Science and Technology, Via La Masa, 34, 20156, Milano - Italy. E-mail: michelle.lavagna@polimi.it.
[‡‡] ASI (Italian Space Agency), Via del Politecnico snc, 00133, Roma - Italy. E-mail: roberto.bertacin@asi.it.

IAA-AAS-CU-20-01-05
AAS 20-205

TRAFFIC PREDICTION MODEL FOR BROADBAND MICROSATELLITES CONSTELLATIONS

Roman Korobkov,[*] Petr Mukhachev,[†] and Dmitry Pritykin[‡]

This study is a part of a general constellation design project conducted in Skoltech Space Center. The main objective of our work is to outline and validate a procedure to derive preliminary requirements for a microsatellite in a constellation to provide global internet service. Thus, we consider an orbital motion of all satellites within a given constellation pattern (e.g. Walker delta, Walker star, some flower constellation line-ups, etc.), the service provided to potential global customers (accounting for the satellite coverage geometry, world population density models, and the internet traffic demand). The latter models are based on the 2020 NASA Socioeconomic Data and Applications Center gridded population count map. For more precise predictions, the following factors are taken into account for each point in the satellite field of view: time (accurate to one hour), population, country and internet penetration rate in that country respectively. Finally, given the estimated required single-satellite link-budget, we proceed to analyze an inter-satellite laser communication subsystem, which, in turn, drives the requirements to attitude control and electrical power satellite subsystems. [View Full Paper]

[*] Space Center, Skolkovo Institute of Science and Technology, Moscow Oblast, Russia, 143026. E-mail: r.korobkov@skoltech.ru.
[†] Space Center, Skolkovo Institute of Science and Technology, Moscow Oblast, Russia, 143026. E-mail: p.mukhachev@skoltech.ru.
[‡] Space Center, Skolkovo Institute of Science and Technology, Moscow Oblast, Russia, 143026 E-mail: d.pritykin@skoltech.ru.

IAA-AAS-CU-20-01-06
AAS 20-206

METHODS FOR ACCURATE BALLISTICS CALCULATIONS FOR MULTI-SATELLITE CONSTELLATIONS

Natalia A. Zavialova,[*] Egor V. Pliashkov,[†] Aleksandr A. Kuznetsov,[‡] Vadim Yu. Semaka,[§] Vladimir A. Panov,[**] Ivan N. Zavialov,[††] Ilya I. Fukin,[‡‡] and Sergei S. Negodiaev[§§]

Currently, the number of spacecrafts and space objects in near Earth orbit is steadily increasing. For their simulation the fast and accurate methods are required. The main goal of this work was an attempt to reduce the computational complexity of ballistic calculations. To solve this problem, a method for interpolating the gravitational potential using bicubic splines is proposed. The method demonstrated its accuracy and the ability to carry out calculations much faster than using the usual Earth potential. [View Full Paper]

[*] Moscow Institute of Physics and Technology, Russia. E-mail: zavialova.na@mipt.ru.
[†] Moscow Institute of Physics and Technology, Russia. E-mail: pliashkov.ev@mipt.ru.
[‡] Moscow Institute of Physics and Technology, Russia. E-mail: kuznetsov.aa@mipt.ru.
[§] Moscow Institute of Physics and Technology, Russia. E-mail: semaka.viu@mipt.ru.
[**] Moscow Institute of Physics and Technology, Russia. E-mail: panov.va@mipt.ru.
[††] Moscow Institute of Physics and Technology, Russia. E-mail: zavialov.in@mipt.ru.
[‡‡] Moscow Institute of Physics and Technology, Russia. E-mail: fukin.ii@mipt.ru.
[§§] Moscow Institute of Physics and Technology, Russia. E-mail: negodiaev.ss@mipt.ru.

SPACE DEBRIS

Session Chair:
Sergei Schmaltz

IAA-AAS-CU-20-02-02
AAS 20-209

LABORATORY STUDY OF CONTROL ALGORITHMS FOR DEBRIS REMOVAL USING CUBESAT

Danil Ivanov,* Filipp Kozin,† and Mahdi Akhloumadi‡

Laboratory simulation and verification is a widely-used way to test the accuracy and performance of the control algorithms and the operation of the whole satellite motion control system. Laboratory facility in Keldysh Institute of Applied Mathematics allows to imitate planar translational and one degree-of-freedom rotational motion of nanosatellite mock-ups. Two mock-ups with thrusters imitators on-board are able to move freely along the aerodynamic table due to air cushion. Space debris removal in near-Earth orbits is an actual problem, and a set of international projects is aimed at its solution. Some of the proposed missions rely on the launch of special small satellites able to capture a non-cooperative tumbling object and change its orbit using a propulsion system. This paper is devoted to experimental study and performance comparison of the control algorithms for docking to a non-cooperative tumbling space debris mock-up using 3U CubeSat. Virtual potentials and Lyapunov-based control approaches are implemented; visual-based relative motion estimation is used. The paper presents the results of the experimental verification of the proposed algorithms. [View Full Paper]

* PhD, Space Systems Dynamics Department, Keldysh Institute of Applied Mathematics RAS, Miusskaya sq. 4, 125047, Moscow, Russia.
† Mr., Space Systems Dynamics Department, Keldysh Institute of Applied Mathematics RAS, Miusskaya sq. 4, 125047, Moscow, Russia.
‡ Mr., Theoretical Mechanics Department, Moscow Institute of Physics and Technology, Insitutsky lane 9, 141701, Dolgoprudny, Moscow region, Russia.

IAA-AAS-CU-20-02-03
AAS 20-210

SPACE DEBRIS MITIGATION: CRANFIELD UNIVERSITY'S FAMILY OF DRAG AUGMENTATION SYSTEMS

Zaria Serfontein,[*] Jennifer Kingston,[†] Stephen Hobbs,[‡] and Ian Holbrough[§]

Space debris has become a significant concern for the whole space industry and is growing in importance for the smallsat community. Ever since the start of the space age, there has been more debris in orbit than operational satellites. If the challenge of space debris is not addressed, the amount of debris through collisions could increase exponentially, eventually rendering spaceflight too dangerous to conduct in some orbits. Pressure for low-cost satellites to meet debris mitigation guidelines is increasing and failure to comply could result in a launch license being denied.

Cranfield University has developed a family of drag augmentation systems (DAS) in response to the growing number of small satellites (10-500 kg) unable to de-orbit from low Earth orbit within 25 years. The DAS are lightweight sails deployed at end of mission, and are cost-effective, reliable solutions for de-orbiting small satellites and aiding in the sustainable use of space. This paper presents the three successful drag sails designed, manufactured and tested at Cranfield University and will discuss the findings from recent studies exploring scalability of the sails and the short- and medium-term deployment dynamics of two deployed DAS sails. DAS appear to be a practical and effective means for small satellites to operate sustainably. [View Full Paper]

[*] Cranfield University, Cranfield, Wharley End, Bedford MK43 0AL, United Kingdom.
E-mail: Z.Serfontein@cranfield.ac.uk.
[†] Cranfield University, Cranfield, Wharley End, Bedford MK43 0AL, United Kingdom.
E-mail: J.Kingston@cranfield.ac.uk.
[‡] Cranfield University, Cranfield, Wharley End, Bedford MK43 0AL, United Kingdom.
E-mail: S.E.Hobbs@cranfield.ac.uk.
[§] Belstead Research Ltd., Ashford, Kent, TN25 4PF, United Kingdom. E-mail: Ian.Holbrough@belstead.com.

IAA-AAS-CU-20-02-04
AAS 20-211

PRELIMINARY ANALYSIS OF DOUBLE STATION METEORS OBSERVATION VIA CUBESAT CLUSTER FLIGHT

Hongru Chen,[*] Nicolas Rambaux,[†] Robin Matha,[‡] and Riad Chelil[§]

The METEORIX CubeSat is planned to observe meteors and space debris. Objectives of this project include determination of the origin of the meteoroids, and characterisation of flux density, which can constrain the environmental models for space and ground activities. To effectively achieve the objectives, this work investigates the 3D measurement of entering objects with two METEORIX CubeSats. The mission operation is assumed in the simplest way; that is, the CubeSats are deployed from the launcher at the same time but in different directions, there is no orbit control afterwards, and the CubeSats will constantly point their cameras in the nadir direction. Through analyses of measurement error, view intersection, and the orbital drift of the cluster flight, we have shown the achievable measurement performance under the simplest operation. [View Full Paper]

[*] Postdoctoral Researcher, IMCCE, Observatoire de Paris, Universite PSL, CNRS, Sorbonne Universite, 77 av. Denfert-Rochereau, 75014 Paris, France.
[†] Assistant Professor, IMCCE, Observatoire de Paris, Universite PSL, CNRS, Sorbonne Universite, 77 av. Denfert-Rochereau, 75014 Paris, France.
[‡] Undergraduate student, Universit Paris-Saclay, Route de l'Orme aux Merisiers, 91190 Saint-Aubin, France.
[§] Undergraduate student, Universit Paris-Saclay, Route de l'Orme aux Merisiers, 91190 Saint-Aubin, France.

IAA-AAS-CU-20-02-05
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AUTOMATIC SPACE DEBRIS DETECTION ON IMAGES

I. Perepechkin,* P. Grishin,† A. Pokrovskaya,‡ and S. Negodiaev§

Space debris is a great threat for all space missions. To prevent collisions, constant monitoring of debris trajectories must be performed. A solution is to use network of optical telescopes with advanced algorithms of image processing and orbit estimation. This work is about an image processing algorithm, which is designed to detect objects on images, captured by various types of telescopes in different operation modes. The algorithm's main idea is to recursively detect objects. Reduction of threshold on each step of recursion is performed. At first the algorithm detects the brightest objects, then the more faint ones. It allows to detect a faint object relatively near to the bright ones. After all bright objects are detected and subtracted from the image, integral transformations of image are performed. In transformed space extremely faint but long streaks become visible and detectable. Last step of the algorithm makes detecting small space debris on low orbits possible. [View Full Paper]

* Mr., Phystech School of Aerospace Technology, Moscow Institute of Physics and Technology, 9 Institutskiy per., Dolgoprudny, Moscow Region, 141701, Russian Federation.
† Mr., Phystech School of Aerospace Technology, Moscow Institute of Physics and Technology, 9 Institutskiy per., Dolgoprudny, Moscow Region, 141701, Russian Federation.
‡ Ms., Phystech School of Aerospace Technology, Moscow Institute of Physics and Technology, 9 Institutskiy per., Dolgoprudny, Moscow Region, 141701, Russian Federation.
§ Ph.D., Phystech School of Aerospace Technology, Moscow Institute of Physics and Technology, 9 Institutskiy per., Dolgoprudny, Moscow Region, 141701, Russian Federation.

IAA-AAS-CU-20-02-06
AAS 20-213

CUBESAT WITH DUAL ROBOTIC MANIPULATORS FOR DEBRIS MITIGATION AND REMEDIATION

Houman Hakima*[*] and Michael C. F. Bazzocchi[†]

With the rapid development of space robotics over the last several decades, a new range of potential applications for space-based robotic manipulators has emerged. Some instances of these applications are in-orbit servicing and refuelling, Solar System exploration, and active debris removal. This paper presents the design concept for a CubeSat that is intended for the removal of debris objects crossing the orbit of the International Space Station, which have been shown to be significant hazards. The spacecraft is designed based on a twelve-unit CubeSat bus, which utilizes commercially available components with substantial space heritage. A pair of three degree-of-freedom manipulators are embedded on the spacecraft, which are intended for the grasping operation of uncooperative target debris objects. A hypothetical space mission is introduced in this paper, where several remover spacecraft are inside dispensing canisters onboard the International Space Station (ISS), ready for deployment immediately after a conjunction event is predicted. A remover CubeSat is deployed long before the predicted conjunction time, which then proceeds to performing a rendezvous and grasping maneuver with the approaching debris object. Upon grasping the object, the angular momentum of the remover and debris system is dumped using the CubeSat's onboard reaction wheels. Then, the system is steered towards a 100-km orbit for reentry into Earth's atmosphere, using the low-thrust propulsion system onboard the remover CubeSat. Three critical attitude and orbital maneuvers are described in this paper, namely, the rendezvous, detumbling, and deorbiting maneuvers. Using the specifications of the remover CubeSat's onboard components, each maneuver is simulated, and the performance of the CubeSat is discussed in light of the results. The results show that the removers are capable of eliminating threats to the International Space Station imposed by conjuncting debris objects, and that such objects can be deorbited in a time frame much shorter than their natural lifetime. [View Full Paper]

[*] Research Assistant, Institute for Aerospace Studies, University of Toronto, 4925 Dufferin Street, Toronto, Ontario, Canada M3H 5T6. E-mail: houman.hakima@utoronto.ca.
[†] Research Coordinator, Department of Mechanical and Industrial Engineering, University of Toronto, 5 King's College Road, Toronto, Ontario, Canada M5S 3G8. E-mail: michael.bazzocchi@utoronto.ca.

SPACE SCIENCE

Session Chair:
Anna Guerman

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OPHELOS: A BIOMEDICAL CUBESAT CONCEPT

Luis Cormier,[*] James Cockayne,[*] Jacek Patora,[*] and Manuel Ibarrondo[*]

The OPHELOS (Orbital Platform Helping Experiment on Living Organisms in Space) program is a project performed by undergraduate and postgraduate students at University of Nottingham with the supervision of professors and other members of staff. The main aim is to observe the behavior of a biological payload in the space environment, which is characterized by microgravity and high levels of ionizing radiation. Through the use of the CubeSat standard, the OPHELOS platform allows a wide range of biomedical research to be performed in this environment, while being able to be constructed in an educational institution and launched aboard many vehicles, at a low cost. A wide selection of instruments can be implemented aboard the platform, including thermal monitoring and control systems, and a radiation dose monitoring system. While the initial mission will perform research to monitor the radiation effects on Caenorhabditis elegans (C. elegans), future missions can be adapted to perform any type of measurements and research on a wide variety of payloads. Development of the platform started in late 2018, progressing towards the current design. A test of the system is planned to be performed on board a high-altitude balloon in 2020, before moving on to a dedicated orbital mission in the future. [View Full Paper]

[*] Department of Mechanical, Materials and Manufacturing Engineering, University of Nottingham, NG7 2RD, United Kingdom.

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MULTI-SATELLITE PROJECT UNIVERSAT – SOCRAT OF CUBESAT SYSTEM FOR SPACECRAFT AND AVIATION RADIATION HAZARD WARNING SYSTEM AND FIRST EXPERIENCE OF MOSCOW UNIVERSITY CUBESAT MISSIONS

Sergey I. Svertilov,* Michail I. Panasyuk,* Vasily L. Petrov,* Vitaly V. Bogomolov,* Anatoly F. Iyudin,* Vladimir V. Kalegaev,* Pavel A. Klimov,* Vladislav I. Osedlo,* Oleg Yu. Peretyat'ko,* Mikhail V. Podzolko,* Yury K. Zaiko,* Ivan A. Zolotarev,* and Ivan V. Yashin*

D.V. Skobeltsyn Institute of Nuclear Physics of the M.V. Lomonosov Moscow State University (SINP MSU) is developing the new project Universat-SOCRAT intended for monitoring of space factors being threats for space missions and aviation. A system of small satellites will be launched into selected orbits crossing the wide range of magnetic drift shells at different altitudes. The primary scope for the project is the operational monitoring of near-Earth's radiation environment, i.e. fluxes of electrons and protons of Earth's radiation belts and energetic particles of solar and galactic origin. These space factors represent a significant health risk for manned spacecraft crew and passengers onboard aircraft. Activity in terms of Universat-SOCRAT project can address so far unanswered questions of detection and dosimetry of ionizing radiation, as well as electromagnetic transients in the optical, UV, X-ray and gamma ranges. The research is applicable to spacecraft such as cubesats, which provide adequate determination of radiation conditions on the flight paths of aircraft. There are also discussed the first results of measurements of charged particles, gamma quantum fluxes and UV-emission from the atmosphere in three cubesat missions, which were successfully launched in July, 2019.

[View Full Paper]

* M.V. Lomonosov Moscow State University, 1(2), Leninskie gory, GSP-1, Moscow 119991, Russian Federation.

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DEVELOPMENT OF A CUBESAT PLATFORM FOR BIOMEDICAL AND PHARMACEUTICAL LEO EXPERIMENTS

Daniel Robson,[*] [†] Chantal Cappelletti,[†] Joel Segal,[†] Phil Williams,[*] and Nathaniel Szewczyk[‡]

Undertaking biology experiments in space is a necessary and important part of understanding evolution, adaption, and ageing, and crucial to the enablement of safe human exploration away from Earth. Access to space, however, is difficult, costly and restricted. As part of a coordinated research programme across many areas of space biology, engineering and medicine, we are developing a 3U CubeSat designed as a flexible platform for conducting experiments in LEO.

The design and development of the platform offers an exciting opportunity for undergraduate and postgraduate researchers. The University will lead the development and verification of hardware and software for the mission, utilising off-the-shelf components and the manufacturing facilities and expertise available at the University.

The first exemplar payload will consist of a small colony of the nematode Caenorhabditis elegans, a model organism used extensively in spaceflight research (Adenle et al., 2009) (Ishioka & Higashibata, 2019). A small, robust, low-power microscope is required for observation of the nematode culture chamber, with data transmission removing the need for physical sample return. The measurements can be used with existing ground control results to verify the University's capabilities to provide the nematodes with a suitably accurate Environmental Control and Life Support System (ECLSS), and the sector with a new, cheap microgravity platform for biological experiments. [View Full Paper]

[*] Astropharmacy & Astromedicine, University of Nottingham, UK.
[†] Department of Mechanical, Materials and Manufacturing Engineering, University of Nottingham, UK.
[‡] School of Medicine, University of Nottingham, UK.

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ASTROBIO CUBESAT: A NANOSATELLITE FOR ASTROBIOLOGY EXPERIMENTS IN SPACE

Andrea Meneghin,[*] John Robert Brucato,[†] Daniele Paglialunga,[‡] Augusto Nascetti,[§] Gianluca Fiacco,[**] Simone Pirrotta,[††] Naveen Odogoudra,[‡‡] Stefano Carletta,[§§] Luigi Schirone,[***] Pierpaolo Granello,[†††] Matteo Ferrara,[‡‡‡] Paolo Teofilatto,[§§§] Sergio Massaioli,[****] Claudio Paris,[††††] Maurizio Parisse,[‡‡‡‡] Lorenzo Iannascoli,[§§§§] Domenico Caputo,[*****] Giampiero De Cesare,[†††††] Mara Mirasoli,[‡‡‡‡‡] Martina Zangheri,[§§§§§] Laura Anfossi,[******] and Liyana Popova[††††††]

AstroBio Cubesat (ABCS) is an Italian 3U CubeSat to be launched with the Vega C maiden flight in summer 2020 at an altitude close to the maximum of the internal Van Allen belt. ABCS host a micro laboratory based on lab-on-chip (LoC) technology able to provide a platform for the automatic execution of bioanalytical experiments. The experiment uses lateral flow immunoassay (LFIA) coupled with hydrogenated amorphous silicon (a-Si:H) photosensors for the detection of the reactions between reagents and target biomolecules immobilized on the strips. The aim is to test the overall system, characterize the LoC device and evaluate the stability of chemicals and biomolecules. The approach, if confirmed by the results, should be the first step to implement a mature technology able to support the search for signs of life in exploration missions, space biolabs without human support and health monitoring in manned missions. [View Full Paper]

[*] Ph.D., Astrophysical Observatory of Arcetri, INAF, andrea.meneghin@inaf.it.
[†] Senior Scientist, Astrophysical Observatory of Arcetri, INAF, john.brucato@inaf.it.
[‡] Eng., Astrophysical Observatory of Arcetri, INAF, daniele.paglialunga@uniroma1.it.
[§] Associate Professor, School of Aerospace Engineering, UNIROMA1, augusto.nascetti@uniroma1.it.
[**] Associate Professor, School of Aerospace Engineering, UNIROMA1, augusto.nascetti@uniroma1.it.
[††] Ph.D., Department of Exploration and Observation of the Universe, ASI, simone.pirrotta@asi.it.
[‡‡] Eng., School of Aerospace Engineering, UNIROMA1, naveensodogoudra@gmail.com.
[§§] Ph.D., School of Aerospace Engineering, UNIROMA1, stefano.carletta@uniroma1.it.
[***] Associate Professor, School of Aerospace Engineering, UNIROMA1, luigi.schirone@uniroma1.it.
[†††] Eng., School of Aerospace Engineering, UNIROMA1.
[‡‡‡] Eng., School of Aerospace Engineering, UNIROMA1.
[§§§] Professor, School of Aerospace Engineering, UNIROMA1, paolo.teofilatto@uniroma1.it.
[****] Associate Professor, School of Aerospace Engineering, UNIROMA1.
[††††] Associate Professor, School of Aerospace Engineering, UNIROMA1, claudio.paris@centrofermi.it.
[‡‡‡‡] Associate Professor, School of Aerospace Engineering, UNIROMA1, maurizio.parisse@uniroma1.it.
[§§§§] Eng., Dept. of Informatics, Electronics and TLC Eng., UNIROMA1, lorenzo.iannascoli@uniroma1.it.
[*****] Associate Professor, Dept. of Informatics, Electronics and TLC Eng., UNIROMA1, caputo@die.uniroma1.it.
[†††††] Associate Professor, Dept. of Informatics, Electronics and TLC Eng., UNIROMA1, decesare@die.uniroma1.it.
[‡‡‡‡‡] Professor, Department of Chemistry “G. Ciamician”, UNIBO, mara.mirasoli@unibo.it.
[§§§§§] Ph.D., Department of Chemistry “G. Ciamician”, UNIBO, martina.zangheri2@unibo.it.
[******] Professor, Department of Chemistry, UNITO, laura.anfossi@unito.it.
[††††††] Eng., SME Kayser Italia, l.popova@kayser.it.

MISSION DESIGN

Session Chair:
Paolo Teofilatto

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AN INSIDE LOOK AT CAPACITY BUILDING AND ITS ROLES INDUSTRY DEVELOPMENT IN THAILAND

Kittanart Jusatayanond*

Space industry in South East Asia can be said that it is very much at its inception stage. While there might not be a shortage of keen investors, there is a serious shortage of engineers and experts in the field. Recognizing this problem, Astroberry organized a 3-year satellite technology foundation course aimed at educating high-school students. The course is a project-based course that addresses both theory and hands-on where at the end of the 3 year, the students will develop a 1U CubeSat, launch it into orbit in space, and operate the satellite. All activities are under our expert's strict guidance and supervision. The program received tremendous interest by the public at large and it led us to our second project where a constellation of five 1U CubeSats will be developed by students from five different high-schools making it the first high-school satellite constellation in the world. The presentation not only discuss the details and purpose of both programs but also include the technical concept and main characteristics of the CubeSats in the programs. [View Full Paper]

* Astroberry Limited, CEO, Thailand.

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FLIGHT RESULTS FROM A PASSIVELY MAGNETIC STABILIZED SINGLE UNIT CUBESAT

Danil Ivanov,[*] Merlin F. Barschke,[†] Mikhail Ovchinnikov,[‡] and Klaus Brieß[§]

BEESAT-3 is an educational single unit CubeSat mission with the objective to demonstrate an S-band transmitter and a small camera in low Earth orbit. As the transmitter uses a patch antenna with an opening angle of eighty degrees for downlink, the satellite needs to be orientated towards the ground station for data transmission. Considering the moderate pointing requirements, attitude control was implemented as fully passive system based on a permanent magnet and a hysteresis plate in order to limit the complexity of the spacecraft. However, Sun sensors and gyroscopes were implemented to allow for an evaluation of the attitude alignment while passing the ground station. After the launch of BEESAT-3 in April 2013, no whatsoever signal could be received from the spacecraft. However, after nearly five years in orbit, in January 2018, the first successful contact to the satellite could be established and after a significant upgrade of the ground station antenna all mission objectives could be met in the subsequent months. With this paper we present first orbit results from the evaluation of the performance of the passive attitude control system. [View Full Paper]

[*] PhD, Space Systems Dynamics Department, Keldysh Institute of Applied Mathematics RAS, Miusskaya sq. 4, 125047, Moscow, Russia.
[†] M.Sc., Chair of Space Technology, Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany.
[‡] Prof., Space Systems Dynamics Department, Keldysh Institute of Applied Mathematics RAS, Miusskaya sq. 4, 125047, Moscow, Russia.
[§] Prof. Dr.-Ing., Chair of Space Technology, Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany.

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STECCO, A LASER RANGED NANOSATELLITE

Claudio Paris[*] and Stefano Carletta[†]

The Space Traveling Egg-Controlled Catadioptric Object (STECCO) is a 30 cm x 5 cm x 5 cm PocketQube nanosatellite to be launched in 2020. Its shape and the presence of a passive viscous damper shall allow gravity gradient stabilization of the satellite, with one of the two smaller faces pointing toward nadir. Each one of the two smaller faces will be equipped with one Corner Cube Reflector (CCRs), so that it will be possible to track the satellite and reconstruct its orbit by means of laser ranging. One of the two CCRs will have the back faces coated while the other one will be uncoated: this will allow distinguishing which face is pointing toward the ground, because of the different sensitivity to the polarization of the laser impulses used for ranging. CCRs for STECCO will not be custom built units but will be Commercial-Off-The-Shelf (COTS) ones. Optical tests on the reflectors and on the mounting system will be performed in the thermovacuum and optical test lab of the School of Aerospace Engineering of Sapienza University of Rome.

[View Full Paper]

[*] Dr., Centro Fermi - Enrico Fermi Historical Museum of Physics and Study and Research Centre, Rome, Italy. E-mail: claudio.paris@centrofermi.it.
[†] Dr., School of Aerospace Engineering, Sapienza University of Rome, Italy. E-mail: stefano.carletta@uniroma1.it.

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AN OVERVIEW OF THE ALFA CRUX CUBESAT MISSION FOR NARROWBAND COMMUNICATION

Leandro Ribeiro Reis,[*] Renato Alves Borges,[*] João Paulo Leite,[*] Chantal Cappelletti[†] and Simone Battistini[‡]

The development and operation of a reliable voice and data communication systems in remote or difficult-to-reach areas is still a challenge in the modern world. In this framework, the mission Alfa Crux, based on a nanosatellite system under development at the Laboratory of Simulation and Control of Aerospace Systems (LODESTAR), University of Brasilia (UnB), Brazil, proposes the use of narrow bandwidth to create data and voice connections from low orbit. The Alfa Crux system aims at contributing to improve agricultural monitoring, water level controlling in rivers and reservoirs, as well as improving the communications technology between devices (M2M) and the Internet of Things (IoT), especially in remote regions where communication infrastructures on land are unreliable or cost prohibitive. The main problem addressed in this work concerns the development of a nanosatellite communication system based on UHF amateur radio frequency band. The choice of the frequency band is based on the fact that the use of narrowband in nanosatellite communication systems has relevant characteristics such as energy efficiency, spectrum, reliability, performance, safety, communication range, among others. This paper presents an overview of the communication architecture of the space mission of the Alfa Crux nanosatellite. [View Full Paper]

[*] Electrical Engineering Department, University of Brasilia, DF, 70910-900, Brazil.
[†] Department of Mechanical, Materials and Manufacturing Engineering, University of Nottingham, UK.
[‡] Department of Engineering and Mathematics, Sheffield Hallam University, Sheffield, S1 1WB, UK.

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INSPIREFLY: A UNIVERSITY CUBESAT MISSION SET TO MAKE SPACE LOCAL BY DEMONSTRATING THE FIRST EXTERNAL DISPLAY SCREEN IN THE SPACE ENVIRONMENT

Simran Singh,[*] Benjamin Strickler,[†] Austin Welch,[‡] Matthew Feggeler,[§] Richard Gibbons,[**] and Sam Cullen[††]

In October 2019, the inspireFly team from Virginia Tech won the national SEDS SAT-2 Competition, sponsored via partnership between NanoRacks and small-satellite company Astranis. The undergraduate team's 1U CubeSat, ContentCube, will be deployed from the International Space Station via the NanoRacks CubeSat Deployer in late 2021. In orbit, ContentCube will take a self-portrait (selfie) of its external screen, displaying user-submitted photos, using a deployable boom and attached camera; a tailored thermal management system will maintain nominal temperature for payload components. Equipped with an active attitude determination & control system, the CubeSat will have the capability to maintain any orientation, primarily to retain Earth in the background of its photographed images. ContentCube will take advantage of a customized flight computer, with a system architecture structured around the NASA core Flight System. The team will look to prove the validity of the external display screen via images downlinked to the Virginia Tech Ground Station. In working with industry mentors from NASA, the Ecuadorian Space Agency, and Lockheed Martin, the team has verified the potential for future applications of external display screens on planetary rovers, during extravehicular activity, or for in-situ measurements. The inspireFly team is paving the way for anyone to experience a personalized space adventure. [View Full Paper]

[*] Chief Engineer, inspireFly; Kevin T. Crofton Department of Aerospace & Ocean Engineering, Virginia Tech, Blacksburg, Virginia 24061, United States of America. E-mail: simran10@vt.edu.
[†] Program Manager, inspireFly; Kevin T. Crofton Department of Aerospace & Ocean Engineering, Virginia Tech, Blacksburg, Virginia 24061, United States of America. E-mail: strick20@vt.edu.
[‡] Payload Engineering and Imaging Systems, inspireFly; Kevin T. Crofton Department of Aerospace & Ocean Engineering, Virginia Tech, Blacksburg, Virginia 24061, United States of America. E-mail: austinw9@vt.edu.
[§] Mechanical, Structural, and Thermal Systems, inspireFly; Kevin T. Crofton Department of Aerospace & Ocean Engineering, Virginia Tech, Blacksburg, Virginia 24061, United States of America. E-mail: mwf77@vt.edu.
[**] Telemetry, Avionics, and Power Systems, inspireFly; Bradley Department of Electrical & Computer Engineering, Virginia Tech, Blacksburg, Virginia 24061, United States of America. E-mail: gricha1@vt.edu.
[††] Attitude Determination and Control Systems, inspireFly; Kevin T. Crofton Department of Aerospace & Ocean Engineering, Virginia Tech, Blacksburg, Virginia 24061, United States of America. E-mail: sam16@vt.edu.

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MINI SPACE ELEVATOR DEMONSTRATION BY CUBESAT "STARS"

Masahiro Nohmi*

A mini space elevator demonstration is challenged by CubeSat in Shizuoka university. The first satellite "STARS-C" was released from the International Space Station (ISS) in 2016. It is two CubeSats connected by 100m long Kevlar tether, and the mission was to deploy tether as the first step. Unfortunately, the orbital experiment was not succeeded perfectly, however the tether deployment was confirmed. The second satellite "STARS-Me" was released from the ISS on October, 2018. It is also two CubeSats, but connected by approximately 11m steel tape tether. The mission sequences are: (i) one CubeSat extends the tether; (ii) the climber stowed in the other CubeSat moving on the extended tether. As the result on orbit in the initial phase, CW beacon was confirmed, and also the command turning on the main CPU was successfully received. However, the main mission has not been performed due to communication trouble, and now under operating. The third satellite named "STARS-Me2" is under developing, and planned to be released from the ISS in 2020. It is one CubeSat having a rigid tape tether and a climber which is re-designed. The climber has two both functions to ex-tend the tape tether, and also to move on the tether for itself. [View Full Paper]

* Professor, Department of Mechanical Engineering, Shizuoka University, 3-7-5 Johoku, Naka-ku, Hamamatsu 432-8561, Japan.

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NANOSTAR, A COLLABORATIVE APPROACH TO NANOSATELLITE EDUCATION

J. B. Monteiro[*] and A. Guerman[†]

The CubeSat standard is today used by many universities and companies as an educational and research tool on space systems. The development of a nanosatellite project requires numerous tools and competences, which makes it an excellent training vector. However, it also requires appropriate experience, facilities and resources, which can be difficult to gather. Hence the need to work in a network. NANOSTAR emerges as a project funded by INTERREG-SUDOE through European Regional Development Fund (ERDF) aiming to develop a network of excellence among universities, the regional industry and the scientific ecosystem in order to create a leading collaborative online platform in Europe for nanosatellites. NANOSTAR aims to provide students with a high level of skills in space engineering and project engineering. In the past year, challenges have been proposed and different education strategies have been adopted. This paper describes the project and gives details about the collaborative online platform and the students challenges. The preliminary mission design challenges are presented, as well as the winner solutions to those challenges. Also, it discusses the methods used to motivate and educate the students. Finally, it draws conclusions based on an analysis of the work development and proposes strategies for the future. [View Full Paper]

[*] Fellow Researcher, Department of Aerospace Sciences, University of Beira Interior, 6201-001 Covilhã, Portugal.
E-mail: jorge.emanuel.monteiro@ubi.pt.
[†] Professor, Department of Aerospace Sciences, University of Beira Interior 6201-001 Covilhã, Portugal.
E-mail: anna@ubi.pt.

INTERPLANETARY MISSIONS

Session Chair:
Chantal Cappelletti

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STATION-KEEPING ABOUT SUN-MARS THREE-DIMENSIONAL QUASI-PERIODIC COLLINEAR LIBRATION POINT TRAJECTORIES

Stefano Carletta,[*] Mauro Pontani,[†] and Paolo Teofilatto[‡]

Space missions designed to operate along three-dimensional quasi-periodic orbits in the proximity of the collinear libration points have been proposed since the late 60s. Because of the intrinsic instability of collinear libration point orbits, guidance laws for station-keeping must be developed to maintain the spacecraft sufficiently near the nominal path. We propose the design of a station-keeping strategy suitable for three- dimensional Lissajous libration point orbits in the Sun-Mars system. Due to the nonnegligible eccentricity of Mars orbit, the dynamical framework of the elliptic restricted three-body problem (ER3BP) is considered. Using Hamiltonian formalism and canonical transformations, the linear dynamics associated with the ER3BP in the neighborhood of the Sun-Mars collinear libration points is reduced to a compact representation. Using this approach, trajectories asymptotic to the Lissajous orbit can be represented by a single linear function, depending only on the four in-plane state variables, driving the design of the feedback guidance law. Suitability and performance of the station-keeping strategy at hand is verified by means of numerical analysis, performed by integrating the nonlinear equations of motion. Its compatibility with available low-thrust devices is investigated as well, and this leads to identifying potentially critical scenarios. [View Full Paper]

[*] PhD, School of Aerospace Engineering, Sapienza University of Rome, 00138, Via Salaria 851, Roma, Italy.
[†] Associate Professor, Department of Astronautical, Electrical and Energy Engineering, Sapienza University of Rome, 00138, Via Salaria 851, Roma, Italy.
[‡] Full Professor, School of Aerospace Engineering, Sapienza University of Rome, 00138, Via Salaria 851, Roma, Italy.

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A TRAJECTORY DESIGN FRAMEWORK LEVERAGING LOW-THRUST FOR THE LUNAR ICECUBE MISSION

Robert Pritchett,[*] Kathleen Howell,[†] and David Folta[‡]

The 6U Cubesat, Lunar IceCube (LIC), is a secondary payload of the Artemis-1 mission. Following deployment near Earth, LIC will employ its low-thrust engine to transfer to a highly inclined 100-km by 5000-km lunar orbit. Designing a trajectory from deployment to the science orbit is made challenging by the large change in energy required and the limited control authority of LIC. To address these challenges, a framework is proposed that leverages dynamical structures available in the bicircular restricted four-body problem (BCR4BP) and direct collocation to design the LIC transfer trajectory. Utilizing the BCR4BP enables the perturbing acceleration of the Sun to assist in the required energy change and avoids the additional complexities of an ephemeris model. Furthermore, direct collocation is a robust technique that permits a greater number of initial guesses to be converged to continuous low-thrust transfers. This framework is demonstrated for multiple launch dates and a subset of results are transitioned to a full ephemeris model for validation. The flexibility and robustness of this framework make it well suited for LIC and other small satellites destined for the Moon that must adapt their trajectory to the needs of a primary payload. [View Full Paper]

[*] Ph.D. Candidate, School of Aeronautics and Astronautics, Purdue University, West Lafayette, Indiana 47907, USA. E-mail: pritcher@purdue.edu.
[†] Hsu Lo Distinguished Professor of Aeronautics and Astronautics, School of Aeronautics and Astronautics, Purdue University, West Lafayette, Indiana 47907, USA. E-mail howell@purdue.edu.
[‡] Senior Fellow, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, USA.
E-mail: david.c.folta@nasa.gov.

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MISSION ANALYSIS IN THE BRAKING EFFECT OF A SMALL MICROSATELLITE USING A HYBRID ROCKET ENGINE TO ACHIEVE A MARS ORBIT

Renan Santos Ferreira,[*] Caio Henrique Franco Levi Domingos,[†] Antonella Ingenito[‡] and Paolo Teofilatto[§]

It is scheduled the Chinese mission 2020 to Mars which departs from Earth in July 2020 and reaches the Mars's sphere of influence after 193 days. Given the optimal launch opportunity Earth-Mars, to reach the orbit of Mars it is necessary to decrease the spacecraft Energy to a value less than zero (capture maneuver). In order to provide this amount of energy, a hybrid propulsion system was designed, respecting the size and mass constraints of microsatellites. For this type of analysis, the main parameters that will be analytically considered from the Earth-Mars transfer trajectory are: Departure trajectory; the B-plane coordinates; parameters of the capture orbit; delta-v capture maneuver considering a non-impulsive maneuver with significant interval spacecraft mass reduction due to propellant burnout. The dedicated software for mission analysis will be STK/Astrogator. After the mission analysis, it was verified that the hybrid engine provides a satisfactory delta-v capable of entering the Mars capture orbit. [View Full Paper]

[*] Scuola di Ingegneria Aerospaziale, Sapienza Università di Roma, Italy. E-mail: gba.renan@gmail.com.
[†] Scuola di Ingegneria Aerospaziale, Sapienza Università di Roma, Italy. E-mail: caiohf8@gmail.com.
[‡] Scuola di Ingegneria Aerospaziale, Sapienza Università di Roma, Italy. E-mail: antonella.ingenito@uniroma1.it.
[§] Scuola di Ingegneria Aerospaziale, Sapienza Università di Roma, Italy. E-mail: Paolo.Teofilatto@uniroma1.it.

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CUBESAT PROJECT FOR SOUNDING THE ATMOSPHERE OF MARS

Iskander Sh. Gazizov,[*] Sergei G. Zenevich,[†] Dmitry S. Shaposhnikov,[‡] Dmitry V. Churbanov,[§] Maxim V. Spiridonov,[**] and Alexander V. Rodin[††]

Accurate knowledge about the properties of the atmosphere of Mars is highly demanded in its climate simulation. To contribute to the Martian atmosphere investigation, authors propose the concept of a multichannel laser heterodyne spectroradiometer (MLHS) based on a CubeSat formfactor. The instrument will measure: mixing ratio of CO_2, H_2O, their vertical distribution, and wind speed component along the sounding track. The MLHS developed by the Moscow Institute of Physics and Technology (MIPT) will be utilized for data acquisition with a high spectral resolution of $\lambda/\delta\lambda \sim 10^7$, which allows to completely resolve profile of individual CO_2, H2O lines. The measurements will be performed by a solar occultation method. A multichannel design is to be considered due to a limited time of data acquisition during the Sun transmission. Every measurement will contain a spatial information about each targeted gas concentration and wind speed for the study region by the inverse problem solution based on line contour shape. The dimensions of the CubeSat meet the 6U standard. The on-board data processing system is based on FPGA. The most optimal satellite operation mode is achieved at orbits with the altitude about 400 km and a satellite lifetime near one Martian year. [View Full Paper]

[*] Master Student, Applied Infrared Spectroscopy Lab, Moscow Institute of Physics and Technology (National Research University), Dolgoprudny, 141701, Russia.
[†] PhD Student, Applied Infrared Spectroscopy Lab, Moscow Institute of Physics and Technology.
[‡] Dr., Applied Infrared Spectroscopy Lab, Moscow Institute of Physics and Technology.
[§] Dr., Space Informatics Lab, Moscow Institute of Physics and Technology.
[**] Dr., Applied Infrared Spectroscopy Lab, Moscow Institute of Physics and Technology; A.M. Prokhorov General Physics Institute, Russian Academy of Sciences, Moscow, 119991, Russia.
[††] Dr., Applied Infrared Spectroscopy Lab, Moscow Institute of Physics and Technology; Space Research Institute of the Russian Academy of Sciences (IKI), Moscow, 117997, Russia.

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FEASIBILITY ANALYSIS OF CUBESAT MISSION ON MARS USING A SMALL DEDICATED LAUNCHER AND ELECTRIC PROPULSION

Artur Gustavo Slongo,[*] Nícolas Winckler Musskopf,[*] Samara Herrmann,[*] André Luís da Silva,[†] and João Felipe de Araújo Martos[‡]

This paper presents a feasibility analysis of a mission that consists of launching a CubeSat to Mars orbit, using Electrical Propulsion and a dedicated small Launch vehicle. The use of small satellites for space missions has grown substantially in the last decade due to its simplicity, reduced cost and increased capability. The miniaturization and standardization of the existent platforms reduced cost and design time, facilitating and popularizing the access to space for universities and small companies. Therefore, the use of nanosatellites is one of the major drivers over the growth of investments in dedicated small and even nanolaunchers, due to its versatility on launch windows available for this class of satellites. From this perspective, this paper aims to use state-of-art space technologies applied for missions on Mars exploration, conceptually analysing its applicability. A dedicated rocket to launch the CubeSat into low orbit was preliminary designed. From LEO orbit, we analyzed the capability of electric propulsion being used to propel the CubeSat to the orbit of Mars. The following topics were analyzed: specific thrust required, energy demand for the propellant, mission time and cost for development. Based on the analyzed topics it is possible to affirm that the mission is possible, opening possibilities to use the method for studies on Mars, and even other planets. [View Full Paper]

[*] Research Fellow, Department of Mechanical Engineering, Universidade Federal de Santa Maria, Av. Roraima, 1000 - Santa Maria, RS - 97105-900, Brazil.
[†] Assistant Professor, Department of Mechanical Engineering, Universidade Federal de Santa Maria, Av. Roraima, 1000 - Santa Maria, RS - 97105-900, Brazil.
[‡] Assistant Professor, Department of Mechanical Engineering, Universidade Federal de Santa Maria, Av. Roraima, 1000 - Santa Maria, RS - 97105-900, Brazil.

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INTERPLANETARY COMMUNICATION ARCHITECTURE FOR FUTURE HUMAN SETTLEMENTS

Joshit Mohanty,* Abdelrahman Metwally,† Ruslan Konurbayev,† and Behnoosh Meskoob†

Space 2.0 race has begun, and it aims at exploring residential areas on celestial bodies. The biggest space agency, NASA, has road plans for deep space gateways in the near future. The project is known as “Artemis” aims at putting back humans on the lunar surface by 2024 and settling there. Undoubtedly, such ambitious plans require highly developed infrastructure to satisfy colonists` needs. In particular, reliable communication between the Earth and bases to be implemented. This paper works towards developing a communication architecture for the Martian Community – Earth with minimum latency. Our team proposes to build a data processing center around Mars. Apart from managing communication signals, the center will perform localized data processing for space traffic management, space weather, etc. The data transfer rate will be 512kbps to the nearest relay center. The floating center, powered by 160KW solar array, will also act as a docking and relaxation platform for flights from Moon/Earth. The module will have the freedom to perform orbital maneuvers to stabilize itself for better pointing accuracy on the Martian surface. A constellation of satellites orbiting around Venus has been architected for less delayed communication for Earth-Moon-Mars. These satellites will serve as a relay for most urgent messages and secure data onboard. [View Full Paper]

* Corresponding Author, Student, Space Center, Skolkovo Institute of Science and Technology, Bolshoy Boulevard 30, bld. 1, Moscow, Russia 121205. E-mail: Joshit.Mohanty@skoltech.ru.
† Student, Space Center, Skolkovo Institute of Science and Technology, Bolshoy Boulevard 30, bld. 1, Moscow, Russia 121205.

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MOTHERCRAFT-CUBESAT RADIO MEASUREMENT FOR PHOBOS SURVEY

Hongru Chen,[*] Nicolas Rambaux,[†] Valery Lainey,[‡] and Daniel Hestroffer[§]

The objective of this work is to investigate the application of radio link between the mothercraft and a CubeSat to the geodesy of Phobos. The origin of Martian moons (i.e. Phobos and Deimos) is still unknown. There are possibilities that they are ejected from Mars after an impact, or they are captured C-type asteroid. The knowledge of Phobos interior structure (e.g. homogeneous, porous, or fractured) will lead to better understanding towards its formation as well as the early solar system. The mothercraft and the CubeSat are flown in a safe high quasi-satellite orbit (QSO) and a sustaining low QSO, respectively. Besides the Doppler measurement noise (0.1 mm/s), the ephemeris error of Phobos at least 200 m is found to be very disturbing for Phobos proximity operations. Nevertheless, the relative motion between the high QSO and the low three-dimensional QSO are resistant enough to reveal C_{20}, C_{22}, and θ to an accuracy of 0.3%, 1%, and 0.6% after one week. Such an accuracy can effectively constrain the moment of inertia as well as the interior structure of the target. The inter-sat radiometric measurement can also support the orbit determination of spacecraft with an accuracy of 240 m and 5 cm/s with respect to Phobos. [View Full Paper]

[*] Postdoctoral Researcher, IMCCE, Observatoire de Paris, Universite PSL, CNRS, Sorbonne Universite, 77 av. Denfert-Rochereau, Paris 75014.

[†] Assistant Professor, IMCCE, Observatoire de Paris, Universite PSL, CNRS, Sorbonne Universite, 77 av. Denfert-Rochereau, Paris 75014.

[‡] Senior Astronomer, IMCCE, Observatoire de Paris, Universite PSL, CNRS, Sorbonne Universite, 77 av. Denfert-Rochereau, Paris 75014.

[§] Senior Astronomer, IMCCE, Observatoire de Paris, Universite PSL, CNRS, Sorbonne Universite, 77 av. Denfert-Rochereau, Paris 75014.

LEO MISSIONS

Session Chair:
Paola Gasbarri

IAA-AAS-CU-20-06-01
AAS 20-237

NONLINEAR ORBIT CONTROL FOR EARTH SATELLITES USING LOW-THRUST PROPULSION*

Mauro Pontani† and Marco Pustorino‡

This research is focused on the definition, analysis, and numerical testing an effective orbit control strategy tailored to compensating orbit perturbations, as well as possible errors at orbit injection of low-Earth-orbit microsatellites. A general, systematic approach to real-time orbit control is presented, under the assumption that the satellite of interest is equipped with a low-thrust propulsion system. Two different operational orbits are considered: (a) very-low-altitude Earth orbit and (b) sunsynchronous orbit. A feedback control law based on Lyapunov stability theory is proposed and tested. A steerable, throttleable low-thrust propulsion system with an upper bound on the thrust magnitude is considered. The stability properties and the overall performance over 5 years are investigated for cases (a) and (b). For case (a), the effect of satellite eclipsing on available electrical power is considered as well. Suitable tolerances on the desired (nominal) conditions allow substantial savings in terms of propellant requirements. [View Full Paper]

† Associate Professor, Department of Astronautical, Electrical, and Energy Engineering, Sapienza University of Rome, via Salaria 851, 00138 Rome, Italy.

‡ M.S. Student, Faculty of Civil and Industrial Engineering, Sapienza University of Rome, via Eudossiana 16, 00186 Rome, Italy.

IAA-AAS-CU-20-06-02
AAS 20-238

THREE-AXIS MAGNETIC CONTROL FOR A NANOSATELLITE: PRACTICAL LIMITATIONS DUE TO A RESIDUAL DIPOLE MOMENT

D. S. Roldugin,[*] A. D. Guerman,[†] D. S. Ivanov,[‡] and M. Yu. Ovchinnikov[§]

Engineering challenges of the three axis solely magnetic control for small satellites are discussed. Two satellites are considered. The first one is a 1U CubeSat, the other is 10 kg nanosatellite. Residual dipole moment, aerodynamic torque and control implementation through the pulse-width modulation are covered in the numerical simulation. Kalman filter for the attitude determination and residual dipole estimation are proposed. Three axis magnetic control is proven to be unavailable for CubeSats due to the large residual dipole moment and very low control dipole moment. Larger nanosatellite stabilization accuracy is shown to be low, but in general the three axis magnetic control is viable.

[View Full Paper]

[*] University Beira Interior, Portugal. E-mail: rolduginds@gmail.com.
[†] University Beira Interior, Portugal. E-mail: anna@ubi.pt.
[‡] University Beira Interior, Portugal. E-mail: danilivanovs@gmail.com.
[§] Keldysh Institute of Applied Mathematics, Russia. E-mail: ovchinni@keldysh.ru.

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AAS 20-239

QUATERNION VERSUS ROTATION MATRIX FEEDBACK FOR TIGRISAT ATTITUDE STABILIZATION

Fabio Celani*

The purpose of this paper is to compare the performances between quaternion and attitude rate feedback, and rotation matrix and attitude rate feedback used to stabilize the nominal attitude of Tigrisat nanosatellite. From a mathematical point of view an important difference between the two control laws is that only quaternion feedback can exhibit an undesired behavior known as the unwinding phenomenon. Monte Carlo campaigns show that the two control laws perform comparably in terms of speed of convergence. Moreover, they show that rotation matrix feedback requires less energy.

[View Full Paper]

* Assistant professor, School of Aerospace Engineering, Sapienza University of Rome, Via Salaria 851 00138 Roma Italy. E-mail: fabio.celani@uniroma1.it.

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FLIGHT EXPERIMENTATION WITH MAGNETIC ATTITUDE CONTROL SYSTEM OF SIRIUSSAT1&2 NANOSATELLITES

D. S. Roldugin,[*] D. S. Ivanov,[†] S. S. Tkachev,[‡] R. Zharkih,[§] and A. Kudryavtsev[**]

«SiriusSat-1» and «SiriusSat-2» are educational and space weather monitoring 1U CubeSats. Both satellites were successfully launched from the ISS on August 15, 2018. The attitude control system consists of six air core magnetorquers embedded in the solar panels covering the satellite body. Magnetometer and angular velocity sensor are used for the attitude determination. The well-known Bdot control reduced initial angular velocity after the separation to several degrees per second. The sensors biases were estimated and uploaded to enhance the attitude determination accuracy. Less than one degree per second angular velocity was achieved. Corresponding flight results are covered in the paper. Three-axis solely magnetic attitude control is in preparation for the flight experiment. The attitude is estimated using the magnetometer measurements by the extended Kalman filter. Two-step filter is constructed for the bias shift of the magnetometer estimation and the following attitude estimation. Filter performance is tested on the flight data onboard the satellite engineering model. [View Full Paper]

[*] PhD, Space Systems Dynamics Department, Keldysh Institute of Applied Mathematics RAS, Miusskaya sq. 4, 125047, Moscow, Russia.
[†] PhD, Space Systems Dynamics Department, Keldysh Institute of Applied Mathematics RAS, Miusskaya sq. 4, 125047, Moscow, Russia.
[‡] PhD, Space Systems Dynamics Department, Keldysh Institute of Applied Mathematics RAS, Miusskaya sq. 4, 125047, Moscow, Russia.
[§] Mr., Sputnix Ltd., Technopark "Skolkovo," Bolshoi bulvar 42, building 1, room 3.305, 121205, Moscow, Russia.
[**] Mr., Sputnix Ltd., Technopark "Skolkovo," Bolshoi bulvar 42, building 1, room 3.305, 121205, Moscow, Russia.

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A MULTI-SATELLITE MISSION TO ILLUMINATE THE EARTH: FORMATION CONTROL BASED ON IMPULSIVE MANEUVERS

Shamil N. Biktimirov,[*] Danil S. Ivanov,[†] Tagir R. Sadretdinov,[‡] Basel Omran[§] and Dmitry A. Pritykin[**]

This study examines feasibility of impulsive control to establish and maintain spacecraft formation consisting of microsatellites equipped with large sunlight reflectors. In the appropriate lighting conditions and given right attitude of the reflecting surfaces, such formations can be visible at a point of interest on Earth as pixel images in the sky. It has been shown that any formation, which is fixed with respect to the orbital reference frame, requires continuous control by onboard thrusters resulting in excessive fuel consumption. However, setting special initial conditions for each satellite that send it along a circumference in the orbital reference frame allows all "pixels" to constitute an image that rotates as a whole almost without control. Some control action is still required for all satellites to converge to the relative trajectories after launch and maintain the formation during its lifetime. It appears that aerodynamic-based control works merely for very low orbit altitudes resulting in the shorter lifetime. Therefore, we consider impulsive control with the use of a liquid-propellant propulsion system to gather the formation deployed from a single launch vehicle with nearly the same initial conditions for all satellites and to maintain the required formation geometry during the mission lifetime.

[View Full Paper]

[*] Space Center, Skolkovo Institute of Science and Technology, Russia. E-mail: shamil.biktimirov@skoltech.ru.
[†] Space System Dynamics Department, Keldysh Institute of Applied Mathematics RAS, Russia.
E-mail: danilivanovs@gmail.com.
[‡] Space Center, Skolkovo Institute of Science and Technology, Russia. E-mail: tagir.sadretdinov@skoltech.ru.
[§] Space Center, Skolkovo Institute of Science and Technology, Russia. E-mail: basel.omran@skoltech.ru.
[**] Space Center, Skolkovo Institute of Science and Technology, Russia. E-mail: d.pritykin@skoltech.ru.

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AAS 20-243

CREATING CUBESAT IMAGE DATABASE FOR MACHINE LEARNING BASED ONBOARD CLASSIFICATION FOR FUTURE MISSIONS

Abhas Maskey[*] and Mengu Cho[†]

CubeSats have limited downlink capability and can be especially challenging while downlinking images. Onboard selection of images could save bandwidth and time. One method for selection is through machine learning. To train a model, dataset is required. However, no such dataset is publically available. The objective of this study is to create a database specific to CubeSat for on-orbit image classification which can be deployed in future missions. The paper presents three methods for data collection. Firstly, open data from Sentinel 3A is used to create nadir pointed images. Secondly, images from the International Space Station is utilized to create horizon images. Lastly, the dataset is supplemented by Kyushu Institute of Technology's internal image database from HORYU and BIRDS satellite projects. Data conditioning and augmentation techniques are also provided to extend the dataset resulting into 15,000 images that can be labeled and used for training. [View Full Paper]

[*] PhD Student, Kyushu Institute of Technology, Japan. E-mail: maskey.abhas481@mail.kyutech.jp.
[†] Professor, Kyushu Institute of Technology, Japan. E-mail: cho@ele.kyutech.ac.jp.

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AAS 20-246

NANOSATC-BR3 CONCEPT DESIGN USING MODEL-BASED SYSTEMS ENGINEERING (MBSE)

Artur Gustavo Slongo,[*] Lorenzzo Quevedo Mantovani,[*] Nelson Jorge Schuch,[*] Otávio Santos Cupertino Durão,[†] Fátima Mattiello-Francisco,[†] André Luís da Silva,[‡] Andrei Piccinini Legg[‡] and Eduardo Escobar Bürger[‡]

This work presents the first phases of conceptual design of the NANOSATC-BR3 CubeSat using MBSE (model-based Systems Engineering). The main objective of the NANOSATC-BR, CubeSat Development Program, is to develop capacity building for the Brazilian space sector. The Program has already two nanosatellites: NANOSATC-BR1, which is operational in space, and NANOSATC-BR2, which is planned to be launched in 2020. The NANOSATC-BR3 mission is in its conceptual phase, where stakeholders requirements are elicited, analyzed and a viable concept solution is provided. To develop the mission concept, the work proposes to use an MBSE software with an embedded Systems Engineering method. The stakeholders needs and Project restrictions, the main inputs of this work, were gathered through stakeholders interviews. This information was broken down within the operational, functional and physical aspects, through the MBSE software, resulting in the definition of a viable concept solution derived and traced back to the early stakeholder needs. The use of MBSE was vital for the conceptual phase development, since it highlighted several hidden requirements, providing a better overall system understanding and visualization for all team members and stakeholders as well. The Program and Projects have financial support from both the Brazilian Space Agency (AEB) and from the Ministry of Science, Technology, Innovation and Communications – MCTIC. [View Full Paper]

[*] Southern Regional Space Research Center – CRCRS/COCRE/INPE-MCTIC, in collaboration with the Santa Maria Space Science Laboratory - LACESM/CT-UFSM, Santa Maria, RS, Brazil, E-mail: arturgustavoslongo@gmail.com, lorenzzo.mantovani@gmail.com, njschuch@gmail.com.

[†] National Institute for Space Research (INPE/MCTIC), São José dos Campos - SP, Brazil. E-mail: otavio.durao@inpe.br, fatima.mattiello@inpe.br.

[‡] Federal University of Santa Maria - UFSM, Technology Center, Professors, Santa Maria - RS, Brazil. E-mail: andre.silva@ufsm.br, andrei.legg@gmail.com, eduardoebrg@gmail.com.

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TWO-TIME-SCALE MAGNETIC ATTITUDE CONTROL OF LEO SPACECRAFT

Giulio Avanzini,* Emanuele L. de Angelis,† and Fabrizio Giulietti‡

Attitude stabilization based on active magnetic devices represents a challenging problem, since the generated magnetic torque is constrained on the plane orthogonal to the local direction of the geomagnetic field, making the system instantaneously underactuated. Full actuation can be recovered accounting for the slow variation of the geomagnetic field in the orbit frame. In this work a magnetic controller is presented, driving a LEO satellite to three-axis stabilization in the Nadir-pointing Orbit Frame. The approach extends a recent method developed by the authors for the acquisition of a pure spin condition around a spacecraft principal axis of inertia, while aiming the spin axis in a desired inertially-fixed direction. As a further contribution, the effect of magnetic residual dipoles is mitigated by online estimation. Performance of the proposed control technique is validated by numerical simulations, where parameter uncertainties, corrupted measurements, and control implementation issues are taken into account, together with models of environmental disturbances. [View Full Paper]

* Professor, Department of Engineering for Innovation (DII), University of Salento, Via per Monteroni, Lecce 73100, Italy.
† Research Fellow, Department of Industrial Engineering (DIN), University of Bologna, Via Fontanelle 40, Forlì 47121, Italy.
‡ Associate Professor, Department of Industrial Engineering (DIN), University of Bologna, Via Fontanelle 40, Forlì 47121, Italy.

SYSTEMS

Session Chair:
Mikhail Ovchinnikov

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RUSSIAN – ASERBAIJDSHAN SMALL SATELLITE PROJECT FOR RADIATION MONITORING AND UPPER ATMOSPHERE

V. I. Osedlo,[*] M. I. Panasyuk,[*] P. Abdullaev,[†] G. Agaev,[†] V. V. Bogomolov,[*] R. Gasanov,[†] V. V. Kalegaev,[*] T. Mamedzade,[‡] V. L. Petrov,[*] M. V. Podzolko,[*] A. Proskuryakov,[†] R. Rustamov,[†] A. S. ogly Samedov,[†] H. Seyidov,[†] and S. I. Svertilov[*]

Space experiment with number of instruments on board small satellite is elaborating now by M.V. Lomonosov Moscow State University and Aserbaijan National Aviation Academy. Terrestrial Gamma Ray Flashes (TGF) and magnetosphere electron flux dynamics will be studied during this space mission. The near-Earth orbits with relatively low altitudes (500-8000 km) provide the favourable conditions for the study of space radiation in different areas of the near-Earth space including both trapped radiation and electron precipitation from radiation belts. These goals involve the elaboration of a general scientific concept of satellite experiment, determination of optimal orbits and orientation of spacecraft, determination of parameters and technical appearance of measuring instruments (spectrometers of energetic protons and electrons), requirements for satellite platform, orientation system, data transmission, ground data processing center, mathematical modeling of the experiment. The measurement data, which are planned to be obtained during this experiment, will be subsequently used for the studying of the processes of acceleration and loss of trapped and quasitrapped energetic charged particles in the Earth's magnetosphere, validation of existing and development of new dynamic models of Earth's radiation belts, study of TGFs. [View Full Paper]

[*] M.V. Lomonosov Moscow State University, 1(2), Leninskie gory, GSP-1, Moscow 119991, Russian Federation.
[†] Azerbaijan National Aviation Academy, Baku, Azerbaijan.
[‡] Azercosmos, Baku, Azerbaijan.

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FIRST RESULTS OF UV RADIATION MEASUREMENTS MADE BY AURA DETECTOR ONBOARD VDNH-80 CUBESAT

D. V. Chernov,[*] E. V. Glinkin, P. A. Klimov, and A. S. Murashov

VDNH-80 is a 3U cubsat which was launched on July, 5th 2019 from cosmodrom Vostochny. Scientific payload of the satellite includes UV radiation detector AURA (Atmospheric UV RAdiation). It is a compact detector based on silicon photomultipliers (SiPM) intended to measure radiation in a wide wavelengths band 300-800 nm. The sensor part of the detector consists of 4 SiPMs with different UV filters in front of three of them (UFS1, UFS2, FS6). One SiPM is without filter. A special collimator limits the field of view of the detectors up to 40° (HWHM). Sensitivity of SiPMs is controlled by a specially developed automatic gain control circuit which allows detector to operate in various illumination conditions (from darkest places on the night side of the orbit to a direct sun light). The detector measures UV radiation with a temporal resolution of 1 s, calculates STD of signal to estimate signal variations between measurements and has digital thermometers placed nearby SiPMs. In this work we present detector structure and principles of its operation, as well as results of first measurements. [View Full Paper]

[*] Skobeltsyn Institute of Nuclear Physics of Moscow State University (SINP MSU), 1(2), Leninskie gory, GSP-1, Moscow 119991, Russian Federation.

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ADVANCED GAMMA DETECTOR FOR CUBESATS

Vitaly V. Bogomolov,[*] Yury N. Dementiev,[*] Anatoly F. Iyudin,[*] Artem A. Novikov,[*] Mikhail I. Panasyuk,[*] Sergey I. Svertilov,[*] Ivan V. Yashin,[*] Mikhail V. Korzhik,[†] A. A. Fedorov,[†] D. Yu. Kozlov,[†] A. S. Lobko,[†] V. A. Mechinsky,[†] and G. Dosovitskiy[‡]

Modern technologies allow the creation of nanosatellites for the study of gamma-ray bursts from space (GRB, SGR, Solar flares) and from the atmosphere (TGF). For such observations, we present an advanced gamma detector adapted to the CubeSat format combining small mass and power with a sufficient sensitive area and a high efficiency. Its time resolution is enough to determine the direction to the source by triangulation when a set of the detectors is installed on several satellites, distant from each other for several hundred kilometers. This instrument should consist from a set of scintillating crystals of Ce:GAGG type with total sensitive area ~100 cm^2 viewed by SiPM light sensors. Ce:GAGG crystals have quite high light output (~57000 phot/MeV) and density (~6.7g/cm^3) with sufficiently small decay time of ~80 ns, that ensures a high throughput of the unit. The fast crystals help to realize the high accuracy of the time measurements. The use of a multi-pixel detector allows you to expand the dynamic range, which is especially important when registering TGF. Additional layer of plastic scintillator makes it possible to detect gamma-ray bursts among the electron precipitation, which is especially important when conducting an experiment in polar orbit. [View Full Paper]

[*] M.V. Lomonosov Moscow State University, Russia. E-mail: bogovit@rambler.ru.
[†] Institute for Nuclear Problems Belarus State University, Bobruiskaya str. 11, Minsk, 7220030, Belarus.
[‡] National Research Center “Kurchatov Institute,” Akad. Kurchatov square 1, 9Moscow, 123182 Russia.

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DESIGN AND EXPERIMENTAL SET-UP OF A PARAFFIN BASED HYBRID ROCKET ENGINE TO BRAKE A 24U MICROSATELLITE IN A MARS ORBIT

Caio Henrique Franco Levi Domingos,[*] Sasi Kiran Palateerdham,[†] Antonella Ingenito[‡] and Stefano Vecchio[§]

Propulsion systems for microsatellites usually evolves gas thrusters or electrical systems, since the most of applications require low thrust and high reliability. However, with the recent increasing in the interest to explore Mars, the need of propulsion systems more powerful to put this kind of spacecraft into a Mars orbit is a reality. This paper aims to design a hybrid rocket engine able to brake a 24U CubeSat and insert it into a Mars orbit. The thruster uses paraffin and nitrous oxide as propellants due to the high regression rate of the paraffin and the self pressuring characteristic of the N2O. A thermal analysis of paraffin with additives was performed to verify the increasing in grain physical properties. Besides, the test bench for hybrid rocket engines of the Propulsion Laboratory at the School of Aerospace Engineering (SIA) is presented in order to show the capability to perform future experiments to evaluate the engine designed. [View Full Paper]

[*] Eng., School of Aerospace Engineering, Student. E-mail: francolevidomingos.1920204@studenti.uniroma1.it.
[†] Eng., School of Aerospace Engineering, Student. E-mail: palateerdham.1825254@studenti.uniroma1.it.
[‡] PhD., School of Aerospace Engineering, Professor. E-mail: antonella.ingenito@uniroma1.it.
[§] PhD., University of Rome - La Sapienza, Professor. E-mail: stefano.vecchio@uniroma1.it.

IAA-AAS-CU-20-07-13
AAS 20-262

FORMATION-FLYING SAR AS A SPACEBORNE DISTRIBUTED RADAR BASED ON A MICROSATELLITE CLUSTER

A. Renga,[*] M. D. Graziano,[*] G. Fasano,[*] M. Grasso,[*] R. Opromolla,[*] G. Rufino,[*] M. Grassi,[*] and A. Moccia[*]

Formation Flying Synthetic Aperture Radar (FF-SAR) is defined as a SAR in which the signal emitted by the transmitter and scattered from the area of interest is not collected by a single receiver but by many, conveniently distributed, formation flying, receivers. The concept of distributed aperture can enable new SAR working modes, but more important, thanks to passive operations, can achieve very high performance through a series of very compact, low weight, agile, satellite platforms. Such a distributed space system can be regarded as a system in which the payload functionality is broken apart and distributed among the different elements of the system. While fractionation and formation flying may lead to many advantages, distributed space systems pose a number of technological and operational issues at system and subsystem level. Signal modeling, radar processing, system operations and formation flying aspects are analysed in this paper and an end-to-end space system demonstrator concept is also proposed including 3 satellites working in X-band, flying in a LEO close formation. Mission operations and system budgets are performed at a preliminary level showing the possibility to achieve mission objective by platforms of micro-satellite class (<100 kg). [View Full Paper]

[*] Department of Industrial Engineering, University of Naples "Federico II," Italy. E-mail: marco.grasso@unina.it.

IAA-AAS-CU-20-07-16
AAS 20-265

DEVELOPMENT, QUALIFICATION AND FIRST FLIGHT DATA OF THE IODINE BASED COLD GAS THRUSTER FOR CUBESATS

Javier Martínez Martínez,[*] Dmytro Rafalskyi,[†] Elena Zorzoli Rossi,[‡] and Ane Aanesland[§]

In this work we describe the development process and present the first flight results obtained for the I2T5, the first ever iodine-based propulsion system launched to space in November 2019. The system uses the sublimation of solid iodine to build up a gas pressure in the storage tank, which is then guided to the nozzle. The main challenge of using iodine as a propellant in a cold gas propulsion system is the corrosive nature of the iodine, which is a halogen with moderate chemical activity towards most of the metals including stainless steel, as well as other common substances found in spacecrafts. The acceleration of flows in such system is also a complex task, since the maximum vapor pressure of the propellant is defined by the maximum allowed temperature of operation, chosen to avoid solid-to-liquid phase transition which would result in the need to use precise micro-nozzles. The other challenges, such as the possibility of fragmentation of the propellant with consequent loss of the thermal contact and "bouncing" in microgravity conditions, have also been studied and resolved. Here we present the main approaches to our development process and describe the key solutions which resulted in having a space-ready operational device. [View Full Paper]

[*] ThrustMe, Verrieres-Le-Buisson, France. E-mail: javier.martinez@thrustme.fr.
[†] ThrustMe, Verrieres-Le-Buisson, France. E-mail: dmytro.rafalskyi@thrustme.fr.
[‡] ThrustMe, Verrieres-Le-Buisson, France. E-mail: elena.zorzoli.rossi@thrustme.fr.
[§] ThrustMe, Verrieres-Le-Buisson, France. E-mail: ane.aanesland@thrustme.fr.

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AN FPGA-BASED RISC-V COMPUTER ARCHITECTURE ORBITAL LABORATORY ON A POCKETQUBE SATELLITE

Luigi Blasi, Francesco Vigli, Salim M. Farissi, Antonio Mastrandrea, Francesco Menichelli, Augusto Nascetti, and Mauro Olivieri*

Satellite on-board electronics is subject to sever operating conditions mainly due to the presence of cosmic radiations. This work illustrate the design of a computer board based on FPGA device, devoted to study the resilience of different soft-processor micro-architectures in such a harsh operating environment. The soft-processor cores are fully compliant with the RISC-V RV32I instruction set and are implemented on an ARTIX-7 A100 FPGA. Presently, four variants of the processor core are ready to be used in the on-board computer of a PocketQube satellite and have been extensively verified by fault injection simulations. Here we illustrate the first processor cores that will be implemented along with the system architecture that will be set up on the satellite. [View Full Paper]

* Sapienza University of Rome, Italy.

INVITED LECTURES

AAS 20-267

TO THE MOON AND BEYOND BY CUBESATS: ADVANTAGE OR ADVENTURE?

Mikhail Ovchinnikov*

Cubesats have already become an ordinary instrument for various applications in the near Earth orbits. Single satellites, constellations, formations, swarms etc. compose space networks. Each satellite can be oriented and some of them can maneuver either by means of low thrusters or using external forces like aerodynamic resistance in low orbits or even solar radiation pressure in high-altitude orbits. Cubesat design, fabrication and operation in orbit become more and more industrial, less educational and only a few missions are aimed at studies. The prospection of researchers is currently related to the implementation of Cubesats interplanetary missions to the Moon and even beyond – to asteroids and Mars. There are several Cubesat missions to the Moon fully developed by now. Two Cubesats flew by Mars and a few are scheduled to be pushed to Mars. While hardware technology develops fast the dynamical capabilities of the missions which are defined by the fundamental principles of the space flight dynamics do not change correspondingly. The paper covers some of the dynamics issues of the missions to the Moon and Mars subject to the Cubesat capabilities. [View Full Paper]

* Professor, Dr. of Sci., Space Systems Dynamics Department, Head of the Department at the Keldysh Institute of Applied Mathematics, Miusskaya Sq., 4, Moscow 125047, Russia.

AAS 20-268

NEW FASCINATING CHALLENGES FOR SPACE SYSTEMS: SOFTWARIZATION, AI-BASED ROBOTIZATION AND SUSTAINABILITY. WHICH ROLE FOR CUBESATS?

Marina Ruggieri[*] and Tommaso Rossi[†]

The paper aims at highlighting the major challenges that space systems are already and will increasingly be facing in the medium term. Network architectures, transversal technologies, human-robot cooperation are only some of those challenges. Above all of them, the most important umbrella framework is focused on maintaining and continuing to develop the space network with a sustainability-aware approach that is able to preserve both our Planet and the Space itself. In the above frame, are cubesats active allies and even leading actors of the challenges and scenarios of future space systems? [View Full Paper]

[*] Full Professor in Telecommunications Engineering, Department of Electronics Engineering/CTIF, University of Rome "Tor Vergata," Via Politecnico 1, 00133 Rome, Italy.

[†] Teaching and Research Assistant in Telecommunications Engineering, Department of Electronics Engineering/CTIF, University of Rome "Tor Vergata," Via Politecnico 1, 00133 Rome, Italy.

AAS 20-269

INFANTE MARITIME SURVEILLANCE SATELLITE

A. D. Guerman,[*] D. S. Ivanov,[†] D. S. Roldugin,[‡] S. S. Tkachev,[§] and A. S. Okhitina[**]

The INFANTE small satellite mission is currently designed for the Portuguese home waters coverage. It is equipped with the synthetic aperture radar and multispectral camera. Orbit maintenance is required due to the restrictions imposed by the bus and payload. Namely, the radar operation requires relatively narrow range of orbit altitudes so the orbit should be maintained quite close to the nominal operational one. Orbital and angular motion combined simulation results are provided along with the corresponding maintenance maneuvers. [View Full Paper]

[*] University of Beira Interior, Covilhã, Portugal. E-mail: anna@ubi.pt.
[†] University of Beira Interior, Covilhã, Portugal. E-mail: danilivanovs@gmail.com.
[‡] University of Beira Interior, Covilhã, Portugal. E-mail: rolduginds@gmail.com.
[§] Keldysh Institute of Applied Mathematics, Moscow, Russia. E-mail: stevens_l@mail.ru.
[**] Keldysh Institute of Applied Mathematics, Moscow, Russia. okhitina@phystech.edu.

POSTER PAPERS

AAS 20-270

REVISITING THE RESIDUAL MAGNETIZATION PROBLEM IN CUBESAT MAGNETIC ATTITUDE CONTROL

Anastasiia Annenkova,[*] Anton Afanasev,[†] and Dmitry Pritykin[‡]

We consider a 3U CubeSat attitude control system actuated solely by magnetorquers. It is well-known that one of the biggest obstacles that hinders magnetic control is residual magnetization, which causes a major disturbance torque and a variable magnetometer bias. Our study considers a model of residual magnetization, which comprises a constant magnetic moment, a state-dependent part of the same (for instance, arising in the solar panels whenever they are turned to the Sun) and a white noise component. We show that within certain limits such magnetic moment may be identified by the onboard EKF and compensated by the controller. The procedure can also be employed during ground tests to identify the level of residual magnetization, while it still can be reduced.

[View Full Paper]

[*] Space Center, Skolkovo Institute of Science and Technology, Moscow, Russia.
E-mail: Anastasiia.Annenkova@skoltech.ru.
[†] Space Center, Skolkovo Institute of Science and Technology, Moscow, Russia.
E-mail: anton.afanasev@skolkovotech.ru.
[‡] Space Center, Skolkovo Institute of Science and Technology, Moscow, Russia. E-mail: d.pritykin@skoltech.ru.

AAS 20-271

LESSONS LEARNED AND INITIAL RESULTS FROM BIRDS GROUND STATION NETWORK

Apiwat Jirawattanaphol,[*] BIRDS Partners, and Mengu Cho[†]

Communication time between satellites in the LEO and ground stations are usually limited. Increasing communication data rate may not be an option as it may increase satellite cost and impose more requirements on power generation. Using ground station network for constellation of satellites increases the communication window between satellites and ground stations. BIRDS ground station network (GSN) was established in 2015 to support the missions of BIRDS-1 satellites constellation as part of an educational satellite program named BIRDS at Kyushu Institute of Technology (Kyutech). The GSN propagated into supporting the missions of BIRDS-2 and BIRDS-3 satellites and other small satellites operating on VHF/UHF. Currently, the BIRDS GSN has fifteen member countries with ground stations installed in each country across the world in South America, Africa and Asia connected by internet and managed by Kyutech. This paper presents challenges and lessons learned in establishing ground stations in participating countries such as the insufficiency of technical skills and knowledge to set up and operate the local ground station. The BIRDS GSN has been successful to increase the time resolutions and significantly reduced time to download images from BIRDS-3 satellites.

[View Full Paper]

[*] PhD. Student, Kyushu Institute of Technology, Kitakyushu. Japan. E-mail: p350945@mail.kyutech.jp.

[†] Professor, Kyushu Institute of Technology, Kitakyushu. Japan. E-mail: cho@ele.kyutech.jp.

AAS 20-272

RELIABLE PROTECTION STRATEGY OF POWER DISTRIBUTION MODULE FOR UNIVERSITY CUBESAT

Kamel Djamel Eddine Kerrouche,[*] Lina Wang,[†]
Sidi Ahmed Bendoukhad,[‡] and Arezki Faiza[§]

The Electrical Power System (EPS) for CubeSats consists of four main modules: Photo-Voltaic Solar Module (PVSM) as primary source, Power Storage Module (PSM) as secondary source, Power Regulation Module (PRM) and Power Distribution Module (PDM). The PDM provides functions for the mission in different modes and essential for critical mode, load management (switching on and off subsystems), overcurrent protection and protection against undervoltage. In this paper, reliable protection strategy of the PDM is proposed. Reliable protection is ensured by the use of redundant analog and digital electronic functions to effectively perform the space mission. Electrical schematics and PCB design for the PDM based on reliable protection strategy under CubeSat standards are presented. The analysis and test of the proposed control and protection strategy of PDM are presented to show its effectiveness. [View Full Paper]

[*] PhD, Satellite Development Center, 3100 Oran, Algeria.
[†] Professor, Beijing University of Astronautics and Aeronautics, Beijing, China.
[‡] PhD, Satellite Development Center, 3100 Oran, Algeria.
[§] PhD Student, Satellite Development Center, 3100 Oran, Algeria.

PASSIVE THERMAL COATING OBSERVATORY OPERATING IN LOW-EARTH ORBIT (PATCOOL) – CUBESAT DESIGN TO TEST PASSIVE THERMAL COATINGS IN SPACE

Carlos Ojeda,[*] Tanya Martin,[†] Sanny Omar,[‡] Michael Kennedy,[§] Brandon Paz,[**] Riccardo Bevilacqua,[††] and Brandon Marsell[‡‡]

The PATCOOL is a NASA sponsored, University of Florida developed 3U CubeSat meant to investigate the feasibility of using a cryogenic selective surface coating as a new, more efficient way of passively cooling components in space. Initial tests on the ground demonstrate that this coating should provide a much higher reflectance of the Sun's irradiant power than any existing coating, while still providing far-infrared power emission. The ultimate validation of this technology requires on-orbit testing. PATCOOL hosts a 4-sample housing, with the samples shaped as thin cylinders (coin-like). Two samples are coated with state-of-the-art material, while the other pair uses the new coating to be evaluated. The temperatures of all samples during the mission (minimum 72 hours of data collection) are measured via thermistors. The samples are connected via thin Kevlar strings to the housing, to minimize heat transfer. The housing is designed to shield the samples from Earth's thermal radiation, and the CubeSat is attitude stabilized and controlled via a gravity gradient boom, magnetorquers and a reaction wheel set. Thermal Desktop simulations show PATCOOL's ability to thermally isolate the samples from heat exchanges other than with Sun and deep space, thanks to its thermal design and the chosen attitude profile. [View Full Paper]

[*] Post-Master's Associate, Mechanical and Aerospace Engineering, University of Florida, 939 Sweetwater Dr., Gainesville, Florida 32611, USA.

[†] Graduate Student, Mechanical and Aerospace Engineering, University of Florida, 939 Sweetwater Dr., Gainesville, Florida 32611, USA.

[‡] Post-Doctoral Associate, Mechanical and Aerospace Engineering, University of Florida, 939 Sweetwater Dr., Gainesville, Florida 32611, USA.

[§] Undergraduate Student Researcher, Mechanical and Aerospace Engineering, University of Florida, 939 Sweetwater Dr., Gainesville, Florida 32611, USA.

[**] Post-Bachelor's Associate, Mechanical and Aerospace Engineering, University of Florida, 939 Sweetwater Dr., Gainesville, Florida 32611, USA.

[††] Associate Professor, Mechanical and Aerospace Engineering, University of Florida, 939 Sweetwater Dr., Gainesville, Florida 32611, USA.

[‡‡] Aerospace Engineer, NASA, Kennedy Space Center, Florida 32899, USA.

AAS 20-274

THE DEVELOPMENT OF THE MEDIUM ENERGY CHARGED PARTICLES DETECTOR FOR CUBESAT SPACE MISSIONS

V. L. Petrov,* M. I. Panasyuk,* S. E. Kochepasov,* V. I. Osedlo,* S. A. Filippychev,* M. V. Podzolko,* and V. V. Bengin*

The development of the multi-purpose spectrometer of electrons with energies ~0.1…10 MeV, protons with energies ~2…160 MeV and α-particles with energies of several MeV for installation in CubeSat format is presented. The main element of the spectrometer is a telescope assembly, including semiconductor (silicon) detectors with different thickness, which are placed coaxially one under the other. To measure the pitch-angle distribution and omnidirectional fluxes, several telescopes with differently directed axes can be used. Direct measurement of omnidirectional particle fluxes can be realized using spacecraft rotation. The axis of rotation should be perpendicular to the Equatorial plane. An active orientation system of the spacecraft is not critical for mission success, but the availability to point exact directions with accuracy not less than 5° can significantly expand scientific mission objectives. The main operational mode is when all detectors are switched-on and operate continuously. Instrument switching between operational modes is carried out by commands from the ground station or by the internal scheduler of the control unit. To optimize the payload energy consumption, several energy-saving modes to be implemented (different sampling rates from full-speed operating up to partial switching-off).

[View Full Paper]

* D.V. Skobeltsyn Institute of Nuclear Physics of M.V. Lomonosov Moscow State University, Moscow, Russia.
E-mail: vas@sinp.msu.ru.

AAS 20-275

NANOSATC-BR2 LAUNCH – THE NANOSATC-BR CUBESAT DEVELOPMENT PROGRAM STATUS AND FUTURE

Nelson Jorge Schuch,[*] Rodrigo Passos Marques,[*] Fernando Sobroza Pedroso,[*] Fábio Batagin Armelin,[*] Thales Ramos Mânica,[*] Leonardo Zavareze da Costa,[*] Lorenzzo Quevedo Mantovani,[*] Artur Gustavo Slongo,[*] Jose Valentin Bageston,[*] Juliano Moro,[†] Otávio Santos Cupertino Durão,[‡] Marlos Rockenbach da Silva,[‡] Odim Mendes,[‡] Fátima Mattiello-Francisco,[‡] Danilo Pallamin de Almeida,[‡] Andrei Piccinini Legg,[§] André Luís da Silva,[§] João Baptista dos Santos Martins[§] and Eduardo Escobar Bürger[§]

This work first discusses the launch of NANOSATC-BR2, as well as the status of the NANOSATC-BR, CubeSats Development Program, the related Capacity Building Program (CBP), and its future. The current status refers to the realization of two CubeSats, NANOSATC-BR1 or NCBR1, (1U) and NANOSATC-BR2 or NCBR2, (2U): requirements, solutions, and science goals. The NANOSATC-BR1 was launched by a DNEPR launcher, at the Yasny Launching Base, in Russia, on June 19th, 2014. The NANOSATC-BR2 launching is scheduled for 2020, from a Russian base yet to be determined. The INPE-UFSM's CBP has the involvement of UFSM's undergraduate students, graduate students from other institutions, and the participation of INPE/MCTIC's graduate students that develop activities in the Onboard Data Handling (OBDH) subsystem, Verification, Validation and Integration Testing for the NANOSATC-BR2. Students do the entire operation of the two NANOSATC-BR 1and 2 Projects Ground Stations (GS) with VHF/UHF bands antennas. For the future, the programmed launch of more two NANOSATC-BR (3 and 4) will provide Brazil with the very first CubeSats constellation. The Program has financial support from the Brazilian Space Agency (AEB) and from the Brazilian Ministry of Science, Technology, Innovation, and Communications - MCTIC. [View Full Paper]

[*] Southern Regional Space Research Center – CRCRS/COCRE/INPE-MCTIC, in collaboration with the Santa Maria Space Science Laboratory - LACESM/CT-UFSM, Santa Maria, RS, Brazil. E-mail: njschuch@gmail.com, rodrigo_marques198@hotmail.com, fespedroso.rs@gmail.com, fabio.armelin@inpe.br, thalesrmanica@gmail.com, leonardozavareze@gmail.com, arturgustavoslongo@gmail.com, lorenzzo.mantovani@gmail.com, bageston@gmail.com, juliano.moro@inpe.br.

[†] State Key Laboratory of Space Weather, Beijing, China.

[‡] National Institute for Space Research (INPE/MCTIC), São José dos Campos - SP, Brazil.
E-mail: otavio.durao@inpe.br, marlos.silva@inpe.br, odim.mendes@inpe.br, fatima.mattiello@inpe.br, danilopallamin@gmail.com.

[§] Federal University of Santa Maria - UFSM, Technology Center, Professors, Santa Maria - RS, Brazil.
E-mail: an-drei.legg@gmail.com, andre.silva@ufsm.br, batista@inf.ufsm.br, eduardoebrg@gmail.com.

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